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A MANUAL
OF
HISTOLOGY

RADASCH

A MANUAL
OF
HISTOLOGY

BY

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WITH 307 ILLUSTRATIONS

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TO MY
FRIEND AND COLLEAGUE
PROF. RANDLE C. ROSENBERGER
THIS VOLUME IS
AFFECTIONATELY DEDICATED

PREFACE

The science of Histology has advanced so much since the first appearance of the predecessor of this volume, that a sufficiently adequate presentation of the subject for students requires more space than the usual amount available in a quiz compend. The compend was, therefore, utilized as a basis for this expansion and has been incorporated into the text of the Manual.

The Chapter on Technic, or Practical Histology, has been enlarged to meet the requirements of routine work in Laboratories of Normal and Pathologic Histology and Hematology. The other Chapters have been materially increased, especially that of the Nerve System. In this a general consideration of the External Anatomy, or Morphology of the Brain, has been given in a sequential manner and the Internal Anatomy, or Histology, has been taken up in the same manner. The various Pathways have been given separate consideration so that this Chapter will be of use to those studying Neuroanatomy and Neuropathology.

Many illustrations have been added from various sources and 40 photomicrographs have been utilized.

The writer desires to thank Dr. J. I. Fanz for his assistance in the preparation of some of the photomicrographs and Dr. Clarence Hoffman for the preparation of the dura showing Sharpey's fibers. The writer is also indebted to the publishers for their courtesies and assistance in the selection of illustrations.

The author trusts that this volume will meet with the same appreciation and success as the compend.

H. E. Radasch.

Wynnewood, Pa.

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PRACTICAL HISTOLOGY

CHAPTER I

TECHNIC

For a thorough understanding of Histology a knowledge of **technic** is requisite, as sections for study must be properly prepared, and this requires skill and care.

Tissues may be studied in a *fresh* or *living* condition as well as after fixing and staining. Muscle, tendon and fibrous tissue may be placed upon a slide with a little normal salt or Ringer's solution or glycerin and gently torn apart with needles. Ringer's solution is prepared as follows:

Sodium chlorid	90.0
Potassium chlorid	4.2
Calcium chlorid (anhydrous)	2.4
Potassium bicarbonate	2.0
Distilled water	10,000.0

Peritoneum, *mesentery* or *omentum* may be spread upon a slide, covered with salt or Ringer's solution and a cover-glass and then studied. *Ciliary action* may be shown by placing a small piece of the gill of a clam upon a slide and keeping it moist with salt or Ringer's solution. The *circulating blood* in the web of a frog's foot may be studied by using a special stage for the support of the frog. The effect of *heat* and *cold* may be studied by the use of a special stage permitting a flow of hot or cold water.

Tissues may be subjected to the action of special agents as *blood serum* and *pericardial fluid*. Thin sections may also be made with a double-bladed knife or the fresh tissue may be frozen and cut in a special freezing microtome.

Maceration is employed to separate tissues by dissolving or softening certain ones and unaffecting others. The latter may be isolated then by shaking.

1. **Hydrochloric Acid. 20 Per Cent. Aqueous Solution.**—Place small pieces of tissue therein for twenty-four to forty-eight hours and then wash thoroughly. This is especially adapted for the isolation of uriniferous tubules as it dissolves the interstitial tissue. The tubules may then be mounted in glycerin jelly. If used in the strength of 1 to 250 parts of water this agent will separate voluntary muscles fibers at the discs.

2. **Potassium hydroxid,** as a 20 to 40 per cent. solution, acts in fifteen to sixty minutes for cells of the nails, hairs and epidermis. If smooth or cardiac muscles are used, small cubes of the tissue are placed in a large quantity of the reagent and shaken. When dissociation has been accomplished the tissue is then transferred to a saturated aqueous solution of potassium acetate to neutralize the hydroxid. Later the tissues are washed in water, stained for twenty-four hours in alum carmin, washed with water and mounted in glycerin.

3. **Nitric acid** in a 10 to 20 per cent. aqueous solution or physiologic salt solution may be used to isolate muscle fibers. It requires from twenty-four to forty-eight hours to act. J. B. MacCallum recommends the following for heart muscle: Nitric acid one part, glycerin two parts, distilled water two parts. Small pieces of tissue remain from eight hours to several days in this solution and are then transferred to a 5 per cent. aqueous solution of glycerin.

Schwalbe recommends a 20 per cent. solution of nitric acid, at 40°C. for twenty-four hours, for the isolation of nerve fibers for measurement.

Digestion Method.—The chief agents for this method are **gastric juice** (*pepsin*) and **pancreatic juice** (*trypsin*, or *pancreatin*). Tissues should be fresh or fixed in alcohol only. Pepsin digests collagen and mucin readily and elastin slowly; nuclein is only slowly or not at all affected while keratin, neurokeratin, chitin, fats and carbohydrates not at all. Pancreatin digests elastin, mucin and nuclein readily; collagen, reticulin, chitin, keratin, fats and carbohydrates are not affected.

Tissues to be digested are placed in the solution and the container placed in an incubator at 37°C. for several hours. The process may be carried on in a warming chamber if sections of tissues are utilized.

Kuskow's solution consists of one part of pepsin dissolved in 200 parts of a 3 per cent. solution of oxalic acid. Pieces of hardened ligamentum nuchæ are placed in the freshly prepared solution and are allowed to remain from ten to forty minutes.

Pancreatin.—Add 0.2 or 0.4 per cent. of Mall's or Merck's pancreatin to a 0.3 per cent. solution of sodium carbonate. This is used to demonstrate reticulum tissue in paraffin sections. Remove the paraffin with xylol, wash thoroughly in alcohol and place the sections in ether in a Soxhlet apparatus for several hours to remove the fat. Bring the sections through graded alcohols to water and then place in the digesting fluid for several hours to several days, until all of the cellular elements are removed. Wash with water and stain with an aqueous solution of fuchsin or toluidin blue, then dehydrate, clear and mount.

For *reticulum* frozen sections 40 to 80μ thick are placed for twenty-four hours in the following solution: Pancreatin 5 grams, bicarbonate of sodium 10 grams, water 100 c.c. Wash carefully with water and transfer the sections to a test-tube and shake thoroughly. Then spread the tissue carefully upon a slide to dry. Then allow a few drops of the following stain to dry upon the section: Picric acid 10 grams, absolute alcohol 33 c.c., water 300 c.c. Stain for one-half hour in the following: Acid fuchsin 10 grams, absolute alcohol 33 c.c., water 66 c.c. Wash a moment with picric acid solution, dehydrate, clear with xylol and mount in balsam.

TECHNIC FOR FROZEN SECTIONS

For cutting sections frozen with CO_2 the piece of tissue is placed upon the hard rubber freezing chamber that has been moistened with a little water. The cylinder, that has been fastened to the table, is provided with an outlet tube and a valve; when the tissue is placed in position the valve is gradually opened permitting the CO_2 to enter the freezing chamber, and the freezing process is begun. Freezing should be carried on cautiously. When the specimen is frozen solid it is then set in the automatic feeding microtome and cut at any desired thickness. Congellation should take place slowly and then sections should be cut as nearly 4μ in thickness as possible.

Wright's Method.—1. Place the fresh specimen in a 10 per cent. solution of formalin for about two hours, or it may be boiled for two to three minutes in the same solution but histologic details are not so good.

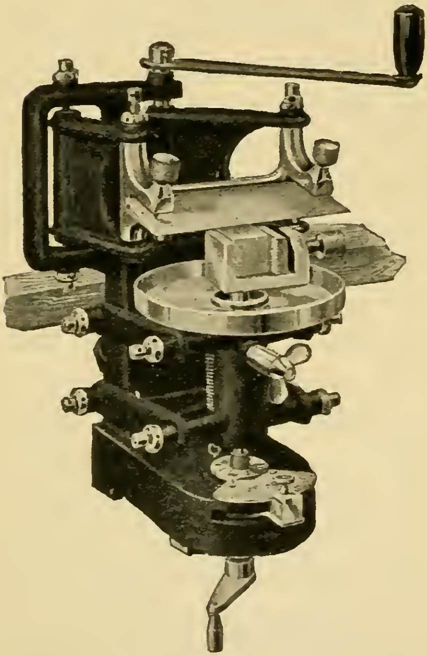

FIG. 1.—AUTOMATIC FREEZING MICROTOME. (*Spencer Lens Co.*)

2. Rinse in water.

3. Cut sections in the freezing microtome.

4. Float the sections upon a slide, smooth out and remove the surplus water.

5. Place a sheet of cigarette paper upon the section, and press this and the section down with a pad of soft, smooth filter paper, the face of which has been moistened with a little 95 per cent. alcohol. Remove the filter paper and carefully strip off the cigarette paper, leaving the section adhering to the slide.

6. Flood the section with absolute alcohol and after thirty seconds drain it off.

7. Flood the section and the adjacent surface of the slide with a thin solution of celloidin, drain the excess off immediately.

8. Flood the slide with 95 per cent. alcohol and then place the slide for ten seconds in water. This hardens the celloidin and prevents the section from curling.

9. Stain with hematoxylin or any combination of stains.

10. Dehydrate in 97 per cent. alcohol.

11. Clear in oil of origanum and mount in balsam.

Rapid Method.—Freeze the tissues, with or without preliminary hardening in formalin and cut sections. Transfer the sections to water and draw upon a clean slide. Drain off the water and dry over an alcohol lamp.

Cover with hematoxylin for two minutes, drain and cover with a 50 per cent. solution of lithium carbonate for one minute (to deepen the stain). Stain with Van Gieson's stain for one minute, wash with water, dehydrate with 95 per cent. alcohol and the absolute alcohol, clear with xylol and mount in balsam.

Some prefer to infiltrate the tissues with a gum mucilage and syrup mixture before freezing.

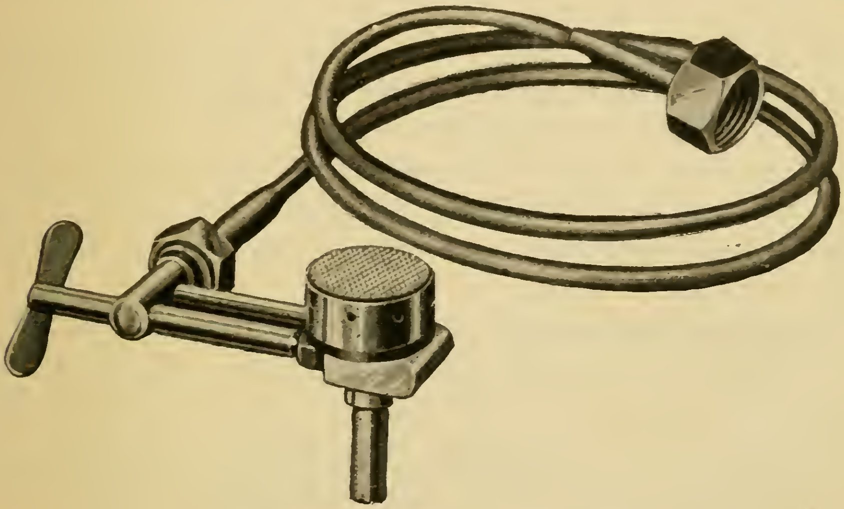

Fig. 2.—Freezing Chamber. (*Spencer Lens Co.*)

ORDINARY TECHNIC

If the freezing method is not used various steps are necessary to prepare a piece of tissue for sectioning, as **Fixation, Dehydration, Clearing, Infiltration** and **Blocking.**

FIXATION

Fixation is the process by which the intercellular substance and the protoplasm of the cells are coagulated by the aid of solutions, or gases, thereby keeping them as nearly like normal as possible. Such solutions are **fixing fluids,** of which there are a great many combinations. Simple fixatives, which are not numerous, will be given first, and under each, its combinations.

Certain salts, as those of chromium, osmium and platinum, interfere with subsequent staining and must be removed by *thorough washing* after fixation. Alcohol, formalin, picric acid, corrosive sublimate and acetic acid are either neutral or favorable to stains.

For fixation, one-quarter inch cubes or slices of organs, ⅛ inch thick and cut at intervals, are the most satisfactory.

1. **Heidenhain's solution** consists of a saturated solution of bichlorid of mercury in a normal salt solution.

Bichlorid of mercury	112 gms.
Sodium chlorid	5 gms.
Water	1000 c.c.

Add the bichlorid to the hot salt solution and when dissolved set aside to cool. The excess of bichlorid will crystallize and keep the solution saturated.

Three to 5 per cent. of *glacial acetic acid* aids the penetration of the bichlorid and assures more thorough fixation.

This solution requires from two to four hours to fix ½-inch cubes.

2. **Potassium Bichromate.**—This salt in a solution of 3½ per cent. strength is a good fixative and hardener. The strength is gradually increased ½ of 1 per cent. by frequent renewal, to 6 per cent., in the course of six weeks. It will not injure tissues left in it for a longer time. It is not often used alone but in combinations mentioned below.

(*a*) **Müller's fluid** depends upon potassium bichromate for its action. Penetration is aided by sodium sulphate.

Potassium bichromate	60 gms.
Sodium sulphate	30 gms.
Water	3000 c.c.

This solution requires from three to six weeks for fixing, but a longer time does not injure the tissues. It is commonly used in the dark, and renewed as often as it becomes cloudy.

(*b*) **Zenker's fluid** is a mixture of *Müller's fluid* and bichlorid of mercury.

Müller's fluid	1000 c.c.
Corrosive sublimate	112 gms.
Mix and add before use	
Glacial acetic acid	50 c.c.

This solution requires from twelve to twenty-four hours to act and should be freshly prepared each time before using.

(*c*) **Zenker-formalin** is made as follows:

Zenker's solution	90 c.c.
Glacial acetic acid	5 c.c.
Formalin	10 c.c.

The last two reagents should be added just before using. This solution requires twelve to twenty-four hours for fixation.

Maximow uses 10 per cent. formalin in place of the acetic acid and the results are said to be excellent.

Helly's Fluid.—This is merely Zenker's fluid in which the acetic acid is replaced by the same proportion of formalin. This is especially adapted for tissues in which the granules of the cytoplasm are to be studied (chromaffin granules, etc.).

(*d*) **Tellyesniczky's fluid** consists of a 3 per cent. solution of potassium bichromate to which is added 5 per cent. of glacial acetic acid (5 c.c. per 100). It is allowed to act twelve to twenty-four hours and then the tissues are thoroughly washed and dehydrated. Nuclei are better preserved by this solution than by the usual bichromate mixtures.

(*e*) **Potassium bichromate** and **formalin**:

Potassium bichromate (3.5 per cent.)	90 parts.
Formalin (40 per cent.)	10 parts.

The tissue may remain in this solution from three or four days to two weeks. It should then be thoroughly washed and dehydrated. This solution answers very well for nerve tissues.

3. **Chromic acid** is generally used in 0.1 to 0.5 per cent. solutions, and should be allowed to act one to eight days, as it penetrates slowly. It is to be frequently changed. It is especially adapted to connective tissues and where mitotic figures are to be studied.

Fixation with chromium salts should be carried on in the dark and thorough washing should follow their use. When corrosive sublimate is used the excess must be removed before staining. This may be done with iodin solution, in block or in sections; the iodin is then removed by means of alcohol or weak solutions of potassium iodid or sodium thiosulphate.

4. **Osmic Acid.**—This reagent is used in 0.5 to 1 per cent. solutions as well as in combination with others. It is a specific reagent for adipose tissue, but if turpentine or alcohol-ether is used for clearing the osmicated fat will be removed. The time for fixation depends upon the strength, usually from twelve to twenty-four hours for 1 per cent. solutions.

Stock solutions may be prevented from reducing by adding sufficient potassium permanganate to impart a slight violet tint. When the solution becomes colorless repeat.

Tissues fixed in osmic acid solution should be washed for several hours in running water and transferred to 90 per cent. alcohol.

(*a*) **Flemming's Solution:**

Osmic acid (2 per cent. solution)	4 c.c.
Chromic acid (1 per cent. solution)	15 c.c.
Glacial acetic acid	1 c.c.

This is the stronger solution recommended by Flemming.

This solution which fixes the tissues in from one to two days, although a longer time will not injure them, should be changed at least once. The tissues are then thoroughly washed and dehydrated. This fluid, which is good for the study of mitotic figures, should be prepared just before using, as it does not keep.

(*b*) **Golgi's Solution:**

Osmic acid (2 per cent. solution)	2 parts.
Potassium bichromate (2 to 2.5 per cent. solution)	8 parts.

Harden for three days in this solution and impregnate with silver nitrate solution. This is used to stain nerve cells and their processes and glial cells.

5. **Formalin** is a saturated solution of **formaldehyde gas** in water. It is not used in full strength, but usually as a 4 to 10 per cent. solution. A 10 per cent. solution is prepared as follows:

Formalin	10 c.c.
Sodium chlorid (5 per cent. solution)	90 c.c.

This requires from twelve to twenty-four hours for its action, and is especially useful in the nerve system. It may be used with potassium bichromate as above given.

6. **Nitric acid** is used as a 3 *per cent. solution,* and small pieces of tissue are allowed to remain therein from one-half to one hour. Large specimens (embryos) require from four to eight hours. After fixation the tissues are immediately transferred to 70 per cent. alcohol.

It is especially adapted to connective tissues, ova, and embryos.

7. **Picrosulphuric Solution** (**Kleinenberg**).—This solution is prepared as follows: To 200 c.c. of saturated aqueous solution of picric acid add 4 c.c. of concentrated sulphuric acid. Allow the precipitate to settle then filter. Dilute the filtrate with 600 c.c. of water. Filter after twenty-four hours if necessary.

This solution is used for the fixation of young embryos and delicate tissues. It requires from one to twenty-four hours. After fixation the embryos are transferred to 70 per cent. alcohol until bleached.

8. **Alcohol.**—There are several strengths of alcohol suitable for fixation. Besides acting as fixatives they at the same time dehydrate.

(*a*) **Absolute Alcohol.**—This should be of at least 99.2 per cent. strength. It acts very rapidly and thoroughly, but its expense prevents its routine use. It must be changed several times. After twenty-four to forty-eight hours the tissues are ready to be cleared.

(*b*) **Ninety-five per cent. alcohol** acts in the same way as the above, but some (Mallory and Wright) hold that shrinkage results if any solution weaker than the absolute alcohol is used. This strength has, however, yielded good results in the nerve system. It must be frequently renewed.

9. **Bouin's Fluid.**—This consists of the following:

Picric acid, saturated aqueous solution..................	75 c.c.
Formalin...	20 c.c.
Glacial acetic acid....................................	5 c.c.

This solution is especially applicable to the fixation of embryos, small ones requiring four to six hours and large ones from twenty-four to forty-eight hours. Specimens, after fixation, should be washed in 70 per cent. alcohol and then 80 per cent. alcohol. This should be changed until the alcohol is no longer colored.

Tissues that have been fixed in solutions containing either *osmic acid or chromium salts must be thoroughly washed* before dehydration. Golgi's method of staining is an exception, as will be seen when its steps are considered.

Blood spreads are readily fixed in a solution of equal parts of **absolute alcohol** and **ether** in which they are allowed to remain from twenty minutes to an hour. Another good fixative is **absolute alcohol,** nine parts, and **formalin,** one part. The time for fixing is about the same.

The blood spreads may be subjected to a temperature of 120°C. for twenty minutes. Ehrlich prefers this method of fixation to the above.

DEHYDRATION

After the tissues have been fixed in one of the above solutions and washed, they are ready for the second step, that of **dehydration.**

Dehydration, or **hardening,** is the removal of the water from the tissues, and is accomplished by alcohols of ascending strengths. The tissues are transferred to a **50 per cent.** solution for six to twenty-four hours, unless otherwise directed. This is followed by immersion in a **70 per cent.** solution for the same time, and then in a **95 per cent.** solution for at least twenty-four hours. During this time, the last should be changed once. To insure perfect dehydration, the specimens, after being drained, may be placed in absolute alcohol for twelve to twenty-four hours.

If the following steps are not to be carried out immediately the tissues should be transferred to a solution of 70 to 80 per cent. alcohol in which they may remain indefinitely.

Tissues fixed in salts of chromium should be dehydrated in the dark.

CLEARING

After dehydration is completed the tissues are ready for the clearing agents.

Clearing or **dealcoholization** is the process by which the alcohol is removed and an agent that will mix with the infiltration medium substituted. If paraffin is to be used, an *oil* or fluid miscible with both alcohol and paraffin is necessary; if celloidin infiltration is to follow, then a mixture of *absolute alcohol and ether* is used.

For the paraffin method the tissues are removed from the alcohol, drained a few minutes and then transferred, usually to an oil, for twenty-four hours. The oil penetrates the tissues, removes the alcohol, and remains in its place.

Chloroform, xylol, and various oils may be employed, among them being *turpentine*, which usually requires twenty-four hours for half-inch cubes.

Xylol requires from six to twenty-four hours, or until the tissue is transparent.

Cedar oil is used as follows: The tissues are first placed in a mixture of *equal parts of cedar oil and absolute alcohol* for twenty-four hours. They are then drained and placed in *pure cedar oil* for the same length of time. If pure oil alone is used, it is changed several times until the tissues are transparent, which usually requires twenty-four to forty-eight hours.

INFILTRATION

After clearing, the tissues are ready for **infiltration.**

Infiltration is the process by which the interstices of the tissue are filled with an agent that hardens and allows the tissue to be cut without distortion. There are two important agents, **paraffin** and **celloidin. Gum** may be used for special purposes. The paraffin method will first be considered.

After clearing, the tissues are drained, blotted with tissue-paper, and then placed in a tube of melted paraffin at a temperature a little above the melting-point, usually 50° to 55°C. This is called **paraffin** No. 1, and its object is the removal of the bulk of the oil. After twelve to twenty-four hours the tissues are removed to a tube of fresh paraffin and allowed to remain the same length of time. This is **Paraffin** No. 2, and the remainder of the oil is removed and pure paraffin left in the tissues. The tissues are then ready to be **blocked.**

By the use of **chloroform,** infiltration with paraffin can be accomplished, to a great extent, in the cold. The tissues are completely dehydrated with absolute alcohol and then placed in **pure chloroform** to replace the alcohol. This is accomplished when the tissues become submerged, usually four to eight hours. They are then transferred to a warm, saturated solution of paraffin in chloroform, for two to four hours, and then to pure melted paraffin until all the chloroform has disappeared (two to twelve hours).

If delicate structures are to be infiltrated they may be cleared slowly by adding **toluol,** or **benzol,** drop by drop, to the specimen in absolute alcohol and mixing after each addition. By this method, 2 c.c. of oil can be added to the same amount of absolute alcohol in four to six hours and no shrinkage result. The specimens may then be transferred to a mixture of absolute alcohol (one part) and toluol (three parts) for one to three hours. They may then be placed in pure toluol from one to four hours, the time depending upon the size, one-eighth to one-fourth inch in diameter. From this it may be transferred to a solution of paraffin in toluol for two to four hours, after which more paraffin is added, and the tube transferred to the paraffin-bath, where it remains for an hour or two, and is then cast.

Acetone-paraffin Infiltration.—Fix the tissues as usual, place in weak alcohol for several hours and then transfer to the following mixture:

Acetone	2 vols.
Ether	2 vols.
Water	1 vol.

Allow the tissue to remain as many hours as it is millimeters thick. Transfer to a mixture of equal parts of acetone and ether saturated with paraffin (36° to 40°C. melting point). The tissue should remain here twice as long as in the preceding step. Then transfer to melted paraffin for five to ten minutes for each millimeter of thickness.

BLOCKING

Blocking may be accomplished by the use of *leaden angles, paper boxes,* or *wooden blocks.* The *leaden angles* are of various sizes and are used in connection with brass plates. These are all cooled in ice-water, quickly dried and the angles put into place. A small layer of paraffin is then run into the mold, and the tissue placed therein, and oriented. The mold is then filled with melted paraffin, and as soon as a scum is formed, the whole is immersed in ice-water, and the angles cautiously removed, so that the water can act upon all sides except the bottom. Unless this is done, the paraffin, in cooling rapidly and contracting, will enclose water bubbles that are unnecessary and annoying. A little skill is required to cast successfully. Usually, by this method, the paraffin remains clear, a condition much to be desired.

If **blocks** are used, these should be preferably of oak, an inch and a quarter long, by seven-eighths square. The end is carefully and tightly wrapped with a strip of thin paper, forming a *cup* ½ to 1 inch deep. The specimen is then quickly oriented upon a thin layer of paraffin, and the cup filled with paraffin. It is then set aside and allowed to cool. The enclosed air bubbles rise. The paraffin is usually not clear by this method, but is made so by placing the block for several days upon paraffin bath. The warmth clears the paraffin.

After casting, the blocks are trimmed, and then are ready to be cut with the microtome.

For the **celloidin infiltration** method, **fixation** and **dehydration** are carried out in the same manner as for paraffin, but a different clearing agent is used. A mixture of *equal parts of absolute alcohol and ether* will clear tissues in twenty-four hours, at the end of which time they are ready for the celloidin.

Celloidin, or **pyroxylin,** is prepared as follows: Wash an ounce of celloidin with distilled water, dry thoroughly, place it in a tightly stoppered container and cover with 200 c.c. of absolute alcohol. After several hours add 200 c.c. of ether. A clear solution should result. This may be thinned to any desired consistency by the addition of a mixture of equal parts of absolute alcohol and ether.

After clearing the tissues are transferred to the thin celloidin for one to four days. Transfer the tissues to Stender dishes, cover deeply with celloidin and leave the cover on loosely so as to permit the alcohol and ether to evaporate slowly. This thickens the celloidin and prepares the tissue for blocking.

The most satisfactory way of blocking is to continue the evaporation of the alcohol and ether until the celloidin is fairly firm. Then place the dish in a jar of 80 per cent. alcohol until the celloidin is hard. The celloidin should be transparent. The tissues may then be cut out in block form and preserved in 80 per cent. alcohol until the technician desires to cut them.

Each block is then removed from the alcohol, dried carefully and placed, for a few seconds, in a mixture of equal parts of absolute alcohol and ether, dipped into the thick celloidin and is then placed upon a wooden block that has previously been dipped in the alcohol-ether and thick celloidin. After standing a few minutes in the air the block is transferred to 80 per cent. alcohol until the cementing celloidin is hard and then it is ready to be cut. The cementing celloidin may be rapidly hardened by placing the block in pure chloroform.

It is inadvisable to preserve the mounted blocks in alcohol for any length of time as the tannic acid of the wood seems to affect the stain reaction unfavorably. Preserve the celloidin blocks in 80 per cent. alcohol until sections are wanted, then mount upon the wooden blocks and cut immediately.

If the celloidin is not hard enough, the blocks may be placed, for twenty-four to forty-eight hours, in 80 per cent. alcohol, containing 1 to 5 per cent. of *glycerin.*

Gum.—This infiltration medium is prepared as follows:

Syrup	Cane sugar	28.5 gms.
	Water	30 c.c.
Gum	Gum Acacia	57 gms.
	Water	310 c.c.

Mix together four parts of the syrup, five parts of the gum and to this add nine parts of a saturated solution of boric acid. Filter through muslin.

The tissues are thoroughly washed free of any trace of alcohol, and are then placed in the above solution, and allowed to remain until penetrated, which requires at least twenty-four hours if half-inch cubes are used. A longer time is better. The process is aided by allowing the jar with the tissues to stand in a warm place.

Tissues infiltrated with gum *must be frozen* and cut in a freezing microtome.

SECTIONING

After the above steps have been finished, the tissues are ready to be sectioned.

Paraffin blocks are *cut dry*, the knife of the microtome being placed so that it meets the block squarely. When large objects are cut, it is sometimes necessary to place the knife obliquely. Very thin sections may be straightened for mounting by floating them on warm water. The slide prepared with Mayer's albumen (see p. 53) is then dipped beneath them, and if carefully lifted, the section rests smoothly in place thereon.

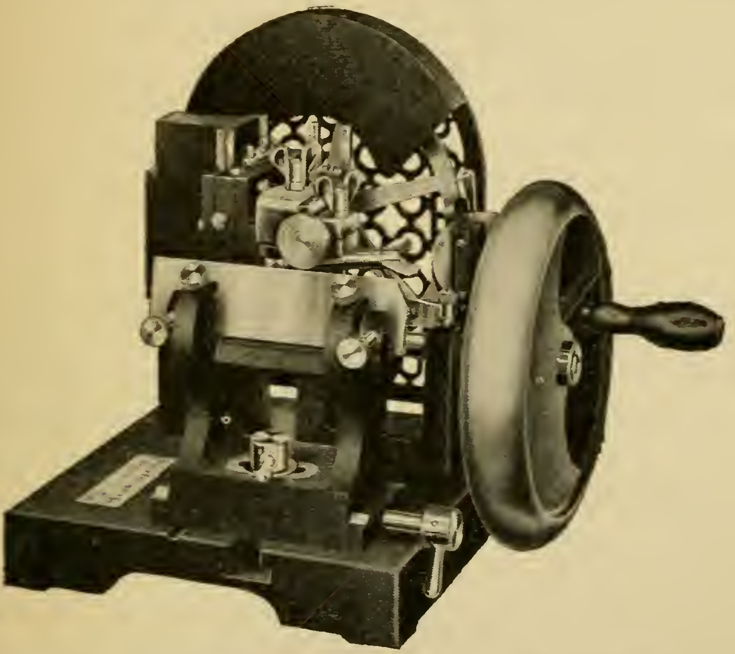

FIG. 3.—MINOT AUTOMATIC ROTARY MICROTOME.
(Bausch and Lomb Optical Co.)

Celloidin blocks are treated differently. The knife is placed obliquely and *kept moist with* 80 *per cent. alcohol.* The block likewise is kept moist, and as the sections are cut, they are transferred, by means of a large sable brush, to a dish of the same strength alcohol, and allowed to remain there until required. If the celloidin is too soft, the sections will be quite thick. This may be remedied by hardening the blocks in alcohol containing 1 to 5 per cent. of glycerin. Celloidin answers very well for the nerve system, but where thin sections are desired, the paraffin method is preferable.

Rapid Technic.—There is a rapid method of technic that gives good results. The steps are as follows:

1. Fix small pieces in **formol-Müller solution** for eighteen to twenty-four hours. (Formol 20 c.c., Müller's solution 80 c.c.)
2. Place in 95 per cent. alcohol for two hours.
3. Fresh 95 per cent. alcohol two hours.
4. Absolute alcohol ($CuSO_4$), twelve to twenty-four hours.
5. Place in anilin oil at 52°C. until transparent.
6. Place in paraffin at 46°C. for one hour.
7. Place in paraffin at 54°C. for three to four hours.
8. Block.

This method requires about fifty-six hours.

STAINING

In order to study the various portions of a cell, they must be differently stained. There are three classes of stains; (1) **Chromatic**, or **Nuclear**, (2) **Plasmatic**, or **Protoplasmic**, and (3) **Special**; of these two are generally used—**nuclear**, or **basic**; and **protoplasmic**, or **acid**. The **nuclear** stain is used *first*, followed by the **protoplasmic stain**; this is called counter-staining. Two stains are used so as to contrast the two main portions of the cell.

Stains are employed in aqueous or alcoholic solutions. The quality of an aqueous solution is better but an alcoholic stain penetrates more rapidly. The quality of the stain reaction often depends upon the fixative used.

Intravitam staining is employed to tinge the cytoplasm of the tissues and cells while these are in the living condition. The living nucleus does not stain.

Nuclear Stains.—The most important of the chromatic stains are hematoxylin and the basic anilin dyes. These depend upon a color base for their action and hence the name *basic stains* is sometimes given to them.

Hematoxylin.—Silver Hematеinate.—(*a*) Dissolve 1 gram of silver nitrate in 100 c.c. of distilled water. To this add 50 c.c. of a 10 per cent. aqueous solution of potassium hydroxid. Shake well.

Allow this to stand for one minute, decant and wash four times by decantation using 150 c.c. of distilled water each time.

(*b*) Dissolve 2.5 grams of hematoxylin in 50 c.c. of absolute alcohol. Pour this upon the silver oxid and heat upon a water bath until the mixture boils, shaking frequently. The mixture should be a deep orange color. Filter. To the filtrate add twenty times its volume of a 5 per cent. solution of potassium alum. The stain is ready for immediate use.

Hematoxylin (Harris).

Hematoxylin	1 gm.
Absolute alcohol	10 c.c.
Potassium alum (sat. aq. sol.)	200 c.c.

Dissolve the hematoxylin in the alcohol and add it to the alum solution. When this is brought to a boil, add 1 gram of mercuric oxid, and cool the solution rapidly. The oxygen liberated ripens the solution immediately, and the stain is ready for use when cool. It should be filtered and diluted with two to three times the quantity of water, when ready, and will require three to five minutes stain.

Carrazi uses potassium iodate as an oxidation agent and claims that his stain will keep for years.

Delafield's hematoxylin is prepared as follows:

Hematoxylin	4 gms.
Alcohol	25 c.c.
Ammonium alum (sat. aq. sol.)	400 c.c.

Dissolve the hematoxylin in the alcohol, and add this solution, drop by drop, to the alum solution. Expose this to the light and air for a week or more, and then filter. To the filtrate add

Glycerin	100 c.c.
Methyl alcohol	100 c.c.

Expose again for a long time, and filter. This solution must be diluted three to four times.

Acid Hematoxylin is made up as follows:

Hematoxylin	1 gm.	
Absolute alcohol	30 c.c.	
Glycerin	60 c.c.	Saturated with alum.
Water	60 c.c.	
Glacial ecetic acid	3 c.c.	

Add the glycerin and water to the hematoxylin, dissolved in the alcohol; then add the acid. This solution must be exposed to the light for three weeks, when it becomes bluish. Sections stained in it are at first not dark, but when exposed to the light, they become bluish.

If the reaction with hematoxylin is not deep enough this may be remedied by washing the section with a little dilute alum solution, or with water containing a faint trace of ammonia.

Most of the **anilin dyes** are not stable, but fade when exposed to the light.

Methylene blue is used in connection with the nerve system and blood.

Methyl green is used for organs and tissues containing *mucin*, and in blood stains.

Safranin O is the best. Mix equal parts of a saturated aqueous and saturated alcoholic solution using absolute alcohol (Lee). Sections remain in this stain from two to twenty-four hours. They are then washed in plain alcohol for thirty seconds to differentiate. Clear in cedar oil, oil of bergamot or xylol and mount in balsam.

The author has found that the saturated aqueous solution produces results in about twenty minutes when the preceding stain has practically no effect.

Bismarck Brown.—This stain is not very soluble in water. A saturated solution is made by boiling the stain in water, and then filtering. This gives a 3 to 4 per cent. solution, which is diluted by adding one-third volume of absolute alcohol. This stains rapidly, but does not overstain. It is used to advantage in contrast with hematoxylin, in connective tissues and cerebellum. It answers well in staining the *acid cells* of the stomach. The sections should first be deeply stained with hematoxylin, and then subjected, five minutes, to the above stain. The *acid cells* are distinctly *brown*, while the *peptic cells* have a *bluish cast*.

Polychrome methylene blue is a *metachromatic stain* and is used diluted ten or even more times. It is allowed to act from ten to twenty-four hours. The sections are then washed with water, covered with water containing glycerin-ether for ten minutes. They are then washed with water, dehydrated with absolute alcohol, cleared with xylol and mounted in balsam. This is an excellent stain for plasma and mast cells. Alcoholic fixation is preferable. The nuclei stain blue, the granules of mast cells are red and those of the plasma cells are blue.

Other basic stains are *toluidin blue*, *thionin*, *dahlia*, *fuchsin*, *gentian violet*, etc.

Plasmatic, or Protoplasmic Stains.—These stain the cytoplasm and intercellular substance. The more common stains are *eosin*, *Van Gieson*, *carmin* and *acid anilin dyes*.

Eosin is the most used plasmatic stain. It is employed after the nuclear stain has been used and washed off. There are a number of eosins, some soluble in water and some in alcohol.

Eosin is commonly used as a 0.5 to 1 per cent. aqueous or alcoholic solution. It requires one to two minutes, and should be washed off with water, if an aqueous solution has been used; otherwise with alcohol.

Eosin is a specific stain for blood-cells and certain granules of the leukocytes, and is, therefore, used extensively in Hematology with methylene blue.

Picric Acid.—A saturated aqueous solution is used for fifteen to thirty seconds. It is then washed quickly with 95 per cent. alcohol.

Picrofuchsin (Van Gieson) consists of **picric acid** and **acid fuchsin.**

Picric acid (sat. aq. sol.)	1800 c.c.
Acid fuchsin (1 per cent. sol.)	85 c.c.

Stain from one to three minutes, and wash with alcohol. A little stronger solution is used for the nerve system. Sections should be cleared in oil of origanum.

There are stains that affect both nucleus and protoplasm sufficiently to differentiate each well. They are used chiefly in **bulk staining,** especially for entire embryos.

Borax carmin consists of **carmin** boiled in a **solution of borax.**

Carmin	2 gms.
Borax (2 per cent. aq. sol.)	200 c.c.

Boil, and then add a few drops of a 5 per cent. solution of acetic acid and 100 c.c. of 70 per cent. alcohol. After a few hours filter, and to the filtrate add a small piece of thymol or menthol, to preserve.

Allow the solution to stain sections for fifteen or twenty minutes, and then differentiate with acid alcohol prepared as follows:

Hydrochloric acid (concentrated)	1 c.c.
Water	29 c.c.
Alcohol (95 per cent.)	70 c.c.

This stain is also used for *bulk staining.*

Alum Carmin.—This is prepared by boiling **1 gram of carmin** with **100 c.c. of a 5 per cent. solution of ammonium alum.** This is filtered when cool, and preserved as above. It also requires the same time for staining.

Picrocarmin is a **double stain,** and its preparation is not so simple. It consists of the following:

Carmin	4 gms.
Ammonia (concentrated)	10 c.c.
Water	200 c.c.

Dissolve the carmin in the ammonia, to which a little water has been added. Then add the water, and, after twenty-four hours, filter. Allow the solution to stand until most of the ammonia has evaporated and add an aqueous saturated solution of picric acid until precipitation occurs. The solution must be stirred all the time. Set it aside to crystallize and to evaporate to one-third of its bulk. Pour off the liquid and evaporate it to dryness. Dissolve the first crystals and evaporate to dryness. This residue, as a 1 per cent. solution in water, is a very good double stain.

Paracarmin consists of the following:

Carminic acid	1	gm.
Aluminum chlorid	0.5	gm.
Calcium chlorid	4	gms.
Alcohol (70 per cent.)	100	c.c.

Dissolve and filter.

This stain is especially useful in **embryology,** as it does not overstain, and may be used again and again. On sections, it is a good contrast stain to Weigert's elastica stain.

Ehrlich-Biondi-Heidenhain Stain.—This stain is used especially in *blood work* or those tissues containing many *leukocytes*. It is composed of:

Orange (G) (saturated aq. sol.)	100 c.c.
Acid fuchsin (Rubin S) (saturated aq. sol.)	20 c.c.
Methyl green (OO) (saturated aq. sol.)	50 c.c.

This solution is diluted to make a solution of 1–100, which, upon the addition of acetic acid, must be bright red. It is difficult to prepare, and so is better bought ready for use.

Tissues should be fixed in corrosive sublimate, and sections stained for twelve to twenty-four hours, washed with 90 per cent. alcohol, and dehydrated with absolute alcohol, cleared and mounted in balsam.

Acid fuchsin is quite soluble in water and is used as a 0.5 per cent. aqueous solution. Sections are stained only a few minutes, washed a few seconds with acidulated water and then with alcohol, cleared and mounted. Sections fixed in chrom-osmium fixatives require twenty-four hours to stain.

Orange G is readily soluble in water and is used in a 0.5 per cent. solution. It is of advantage in blood staining and in mixtures.

Ruthenium red is used in a dilute aqueous solution to stain free-hand cross-sections of dried tendon. The tendon cells and the septa are stained red while the tendon fibers are only slightly affected.

Other plasma stains are *neutral red*, *anilin blue*, *nigrosin*, *light green*, *methyl blue*, *etc.*

Special Stains.—Under this head are classified (1) those that stain by either depositing a coloring substance in the form of a precipitate in certain tissues or spaces, as silver nitrate and gold chlorid; (2) those that have a selective affinity for certain tissues as iron hematoxylin, elastica, reticulum and myelin stains.

The metallic stains, silver nitrate and gold chlorid, produce *negative* or *positive impregnations*. In the *former* the intercellular substances alone are colored, while in the *latter* the cells alone are affected. Lee states that stock solutions of nitrates and chlorids of osmium, uranium, gold, silver and platinum keep better in clear bottles and that a good sunning actually improves them. These metallic stains are used only upon living or very fresh tissues.

Silver Staining.—Corneal Lymph Spaces.—In the solid state silver nitrate may be rubbed over the cornea of a freshly removed eyeball. This surface is then removed, placed in distilled water and then brushed with a camel's hair brush to remove the epithelium. Expose to the light and the silver nitrate that has penetrated the intercellular spaces will be reduced and turned black.

Endothelial Cells.—Remove the omentum, central tendon of the diaphragm or peritoneum of a freshly killed animal, wash in distilled water and stretch over a slide or nested vulcanite rings. Place in a 0.75 per cent. solution of silver nitrate until opaque (ten to fifteen minutes); wash with distilled water and expose to the sunlight until reddish brown; then dehydrate, clear and mount in balsam. The cell outlines are stained black and the nuclei and the cell contents are quite distinct.

Vascular Endothelium.—Into the aorta of a narcotized rat or guinea-pig inject 50 to 80 c.c. of a 1 per cent. solution of silver nitrate. In fifteen to twenty minutes follow this with 100 to 150 c.c. of 4 per cent. formalin and expose to the sunlight. When reduction is complete (reddish brown) remove small pieces of the mesentery, dehydrate, clear and mount in balsam. The endothelium of the vessels will be clearly outlined.

Nerve Cells and Processes.—Cajal-Golgi Method.—Thin pieces of nerve tissue are placed in the following solution and hardened for three days:

1. Potassium bichromate solution (2 to 2.5 per cent.)......	8 parts.
Osmic acid solution (1 per cent.)......................	2 parts.

2. Transfer tissues to a solution of silver nitrate of ½ to ¾ per cent. strength. First blot off the bichromate solution and then rinse tissues thoroughly in some silver solution. Then place tissues in at least thirty times their volume of silver solution and allow them to stand in the dark for three days. Change the silver solution after the first eight to twelve hours.

3. Return to the following solution for one to two days:

Potassium bichromate solution (2 per cent.)	20 parts.
Osmic acid solution (1 per cent.)......................	2 parts.

4. Wash quickly with distilled water and return to a fresh solution of silver nitrate of previous strength for thirty-six to forty-eight hours.

5. Dehydrate in twenty times the bulk of 95 per cent. alcohol for twenty minutes; the alcohol should be renewed after the first five minutes.

6. Dehydrate in same bulk of absolute alcohol for thirty minutes; renew after ten minutes.

7. Replace alcohol by same volume of absolute alcohol and ether (equal parts) for twenty minutes.

8. Transfer to thin celloidin for twenty-five minutes and then thick celloidin for ten minutes.

9. Block and harden in chloroform for about ten minutes.

10. Place for thirty minutes in the following clearing solution:

Carbolic acid (melted)	50 c.c.
Oil of thyme or cedar	50 c.c.
Oil of bergamot	25 c.c.

11. Section, keeping knife and block moist with above clearing fluid.

12. Mount on slides, remove clearing fluid by means of xylol, blot, cover with thick balsam, *but do not use a cover-glass.*

Neurofibrils.—Bielschowsky's Method.—Pieces of tissue 1 cm. in size are fixed in formalin and placed in pyrodin for three to four days. Wash for several hours in frequent changes of distilled water and place in a 3 per cent. solution of silver nitrate at 36°C., for three to five days. Place in an oxid bath for twenty-four hours. Prepare this bath as follows: 20 per cent. solution of silver nitrate 5 c.c.; 40 per cent. solution of sodium hydroxid 5 drops. To this add sufficient ammonia to dissolve the precipitate and then add 100 c.c. of distilled water. This solution keeps only a few hours and should be prepared just before use. After the tissues are taken from the bath wash for a couple of hours in frequent changes of distilled water and reduce in a 20 per cent. solution of formalin, dehydrate and make paraffin sections.

Golgi's Method.—Fix fresh nerve tissues for six to eight hours in a mixture consisting of equal parts of a saturated solution of arsenious acid, 96 per cent. alcohol and 20 per cent. formalin. Place for one to three hours or days in a 1 per cent. solution of silver nitrate. Reduce in the following: hydroquinon 20 grams; sodium sulphate 5 grams; 20 per cent. formalin 50 c.c.; water 1000 c.c. Wash and carry through celloidin. Sections are to be toned in a solution consisting of sodium hyposulphate 30 grams; sulphocyanid of ammonium 30 grams; water 1000 c.c. and 10 per cent. of a 1 per cent. solution of gold chlorid. Tone until gray and then wash carefully and thoroughly, dehydrate, clear and mount.

Silver nitrate solutions (Golgi's method) are also used for outlining the secretory canaliculi of the cells of the liver, acid cells of the stomach, etc.

Gold chlorid gives a *positive impregnation.* It is used somewhat for the study of lymph spaces, but is chiefly used upon nerve tissues for which it seems to have an especial selective affinity. When it is used upon fresh tissues it is called *pre-impregnation* and when it is used upon fixed and hardened tissues it is called *postimpregnation.* In the *former* the nuclei are unstained, the cytoplasm is well stained and the axis-cylinders are reddish violet. In the *latter* the nuclei are well stained, the cytoplasm is pale and the axis-cylinders are black, differentiating the neurofibrils in the latter (Lee). It was formerly believed that the tissues must be fresh for gold staining but it has been found that the results are better if the tissues are put in a cool place for twelve to twenty-four hours before being subjected to the action of the gold chlorid.

Pre-impregnation.—Ranvier's Formic Acid Method.—Take four parts of a 1 per cent. solution of gold chlorid and one part of formic acid and boil. When cool place small pieces of tissue therein: muscle requires about twenty minutes and epidermis one to two hours in the dark. Reduce in the daylight in acidulated water or in the dark in formic acid one part, water four parts, for twenty-four hours. Infiltrate and make sections in the usual way.

Postimpregnation.—Apathy's Method.—Fix tissues in a saturated solution of corrosive sublimate in 0.5 per cent. sodium chlorid and 1 per cent. osmic acid. Infiltration may be in either paraffin or celloidin but should be rapid. Sections are to be fixed to the slide and the bichlorid removed with iodin solution and the latter removed with alcohol. Then wash the sections with water, placed in formic acid for one minute and washed again with water. Transfer, for about twenty-four hours, to a gold chlorid solution (0.1 to 1 per cent.), wash with water and place (sloping) in 1 per cent. formic acid. The sections should face downward so that the precipitate falls away from them. Reduction is carried on in the daylight in summer or in direct sunlight in the winter, for six to eight hours without a break. If the acid becomes brown it should be renewed. Lee recommends a weak solution of formalin, with or without the formic acid, for the reduction.

Iron Hematoxylin.—Place sections for one-half to two hours in a 1.5 to 4 per cent. solution of ferric sulphate (clear violet crystals). Wash with water and stain for one-half hour in a 0.5 per cent. aqueous solution of hematoxylin. Wash with water and transfer to the ferric sulphate to differentiate. Examine frequently under the microscope and continue the differentiation until the stain is removed from all structures except the chromatin and centrosomes. Wash for one-half hour in running water, dehydrate, clear in xylol and mount in balsam. This stain is used for studying the chromatin and karyokinetic figures. The chromatin, centrosomes and spindle fibers are black while the remaining structures are unstained or grayish.

Myelin Stain.—Weigert's Method for Myelin Sheaths.—The tissues are fixed in bichromate, though this is not absolutely necessary. Results are more certain if the tissues have been fixed in a bichromate solution, as they respond more readily to the stains and are not so likely to fade. Celloidin infiltration is usually the best.

After the sections have been cut, they are placed, for four to twenty-four hours, in the following solution:

Potassium bichromate	5 gms.
Chrom alum	2 gms.
Water	100 c.c.

They are then washed thoroughly, and transferred to the following solution for twenty-four hours:

Copper acetate	5 gms.
Acetic acid (36 per cent.)	5 c.c.
Chrom alum	2.5 gms.
Water	100 c.c.

Add the chrom alum to the water, bring to a boil, remove the heat, add the acetic acid, and then the copper acetate, stirring thoroughly until the last of the salt is dissolved. When cold the solution should be clear.

This solution is a *mordant*. The sections are carefully washed and carried into the following solution:

Hematoxylin	1 gm.
Absolute alcohol	10 c.c.
Lithium carbonate (sat. aq. sol.)	1 c.c.
Water	90 c.c.

The sections are stained from fifteen minutes to two or four hours in this lukewarm solution, and then washed and left in the water for twelve to twenty-four hours to deepen the stain. They are then differentiated in the following:

Potassium ferricyanid	5 gms.
Borax (if granular, use one-half amount)	4 gms.
Water	200 c.c.

In this solution they must remain until the gray substance becomes yellowish. This change must be watched under the microscope. The sections are immediately washed with water, and left in water for twelve to twenty-four hours, changing frequently. This fixes the stain. They are then dehydrated, cleared and mounted in balsam.

The myelin sheaths will be bluish-black.

Weigert-Pal Method.—1. Fix as for Weigert method and after cutting place the sections in a ½ per cent. solution of chromic acid for several hours. This step is not necessary if a chromium salt has previously been used for fixation.

2. Wash and transfer to the hematoxylin solution for twenty-four to forty-eight hours. Use the stain lukewarm.

3. Wash with water containing about 2 per cent. of lithium carbonate. The sections should be bluish.

4. Differentiate in a ¼ per cent. aqueous solution of potassium permanganate until the gray substance of the nerve tissue is yellowish-brown in color.

5. Transfer to the following solution until the gray substance is almost colorless:

Potassium sulphit	1 part.
Oxalic acid	1 part.
Distilled water	200 parts.

This solution requires but a few seconds to produce its action.

6. Wash thoroughly with water, dehydrate, clear and mount.

By this method all the tissues, except the myelin sheaths, are decolorized.

Marchi's Method for Degenerated Nerve Fibers.—Harden small pieces of nerve tissue in Müller's fluid for one week, then transfer for a few days to a mixture of two parts of Müller's fluid and one part of 1 per cent. osmic acid solution. Wash thoroughly with water, dehydrate, embed in celloidin and cut sections. Sections should be mounted in chloroform balsam to retain the osmic acid. The normal sheaths are yellow while the degenerated ones are black.

Neuroglia, Mallory's Method.—Fix fresh nerve tissue for four days in 10 per cent. formalin and then transfer for four to eight days to a saturated aqueous solution of picric acid. Mordant for four to six days, at 37°C. in a 5 per cent. solution of ammonium bichromate, imbed in celloidin and section. Place sections for fifteen minutes in a 0.5 per cent. solution of potassium permanganate, wash and transfer for fifteen minutes to a 1 per cent. solution of oxalic acid. Wash well and stain from two to twenty-four hours in phosphotungstic hematoxylin made as follows: Dissolve 1 gram of hematoxylin in 80 c.c. of water, add 20 c.c. of a 10 per cent. solution of Merck's phosphotungstic acid and 0.2 c.c. of hydrogen peroxid (U.S.P.). Wash the sections, dehydrate, clear with oil of origanum and mount in balsam. Axis cylinders and cells are pink while the neuroglia is blue.

To make this stain permanent after washing the hematoxylin off of the sections, place them in a 30 per cent. alcoholic solution of ferric chlorid for five to twenty minutes, wash with water and finish as above. The nuclei and neuroglia are clear blue and other elements are yellowish or grayish.

Nissl's Stain.—This is a special stain for the tigroid bodies of nerve cells. It responds well only in those tissues that have been fixed in 95 per cent. alcohol.

1. Stain.	
Methylene blue (Gruebler's B pat.)	3.75 gms.
Venetian soap (white castile)	1.75 gms.
Distilled water	1000.00 c.c.
2. Differentiating fluid.	
Anilin oil (pure)	10 c.c.
95 per cent. alcohol	90 c.c.

1. Warm the stain until it steams and immerse the sections for four to six minutes.

2. Rinse with distilled water.

3. Differentiate in No. 2 until the sections are pale blue (twenty to sixty seconds).

4. Wash with 95 per cent. alcohol.

5. Clear in a mixture of equal parts of oils of origanum and cajeput and mount in colophonium dissolved in xylol.

The *tigroid bodies* of the cytom and dendrites are a deep blue.

Weigert's elastica stain is used to demonstrate the **elastic tissue** in organs and tissues, and is prepared as follows:

Fuchsin	2 gms.
Resorcin	4 gms.
Water	200 c.c.

This mixture is brought to a boil, and then 25 c.c. of a solution of liquor ferri sesquichlorati added, the mixture stirred and boiled for three to five minutes. When cool, it is filtered, and the precipitate dissolved upon the filter, in 200 c.c. of 95 per cent. alcohol. This is stirred and boiled until the precipitate is entirely dissolved. The solution is then cooled and brought up to 200 c.c. with 95 per cent. alcohol and 4 c.c. of hydrochloric acid added.

Carbolic acid in the same proportion may be used in place of resorcin.

Sections should be stained, from twenty minutes to an hour, in this solution, washed well in 95 per cent. alcohol, counter-stained with picric acid solution for thirty seconds, washed, dehydrated and cleared and mounted. The elastic tissue should be of a bluish-black color.

Osmic Acid.—This is used as a 1 per cent. solution as a special stain for fat, which it turns black and renders almost insoluble in the ordinary reagents used in technic.

Sudan III.—A solution of this stain is also a special stain for fat, coloring it a deep red. Sections are stained from a few minutes to twenty-four hours in a saturated solution of Sudan III in 80 per cent. alcohol. They are washed with 95 per cent. alcohol, then water and mounted in glycerin jelly.

Capsicum red stains the ordinary fat or the fat of sebaceous and ceruminous glands, nerve fibers and fat in pathologic conditions equally well. Sections of fixed tissues or frozen sections may be stained five minutes or longer, washed with 80 per cent. alcohol, then water and mounted in glycerin or glycerin jelly. Sections may be counter-stained with hematoxylin. The stain is prepared by making an alcoholic extract of the ripe capsicum (pericarpium layer) and evaporating this to one-fifth of its bulk.

Cyanin Solution stains fat a bluish color.

Picrofuchsin (Van Gieson).—Although this may be classed under the plasmatic stains, it is, nevertheless, a special stain for white fibrous connective tissue. This it stains a beautiful bright red, while the other tissues are stained yellowish or brown.

Mallory's Reticulum Stain.—Sections (bichlorid fixation) are placed, after the removal of the bichlorid, in a 0.1 per cent. solution of fuchsin for one to three minutes. Wash with water and place in for five minutes in a 1 per cent. solution of phosphomolybdic acid. Wash in two changes of water and transfer for five to twenty minutes to the following:

Anilin blue (aqueous solution)	0.5 gm.
Orange G	2.0 gms.
Oxalic acid	2.0 gms.
Water	100 c.c.

Wash with water, dehydrate, clear in xylol and mount in balsam.

Reticulum, amyloid and *mucin* are *blue* while the other structures are yellow or red.

Amyloid Stain.—Tissues may be stained fresh or after fixation, preferably in alcohol. Stain sections in a weak solution of iodin for three minutes and then wash with water. Treat with a 1 to 5 per cent. solution of sulphuric acid and the color will change from red to blue. Dehydrate, clear in oil of origanum and mount in balsam. The *amyloid material* will be *blue.*

Mucin.—Fix tissues in corrosive sublimate, imbed in paraffin and stain the section, without removing the corrosive sublimate, for five to fifteen minutes in a dilute solution of thionin (2 drops of the saturated solution in 5 c.c. of distilled water). Wash with alcohol. clear in a mixture of oil of cloves and thyme and then oil of cedar and mount in balsam. The *mucin* is *red* and the other substances are blue.

Muchematein (Mayer).—This a special stain for *mucin* and stains in from three to ten minutes. It is prepared as follows:

Hematein	0.2	gm.
Glycerin	40	c.c.
Aluminum chlorid	0.1	gm.
Distilled water	60	c.c.

Mix the hematein and glycerin in a mortar and then add the aluminum chlorid and the water. When mixed add a drop or two of nitric acid to increase its sharpness as a nuclear stain.

Glycogen.—Fix small pieces of tissue in the following for ten to twelve hours:

Trichloracetic acid	9 parts
2 per cent. osmic acid	24 parts
Glacial acetic acid	9 parts
Distilled water	58 parts

Wash with 50 per cent. alcohol for one hour or longer and then imbed in celloidin. Sections are stained with Best's alkalin carmin and counter-stained with blue de Lyon for five minutes (10 grams in 250 c.c. of absolute alcohol). Wash with absolute alcohol, clear with xylol and mount in balsam. Fat is black, *glycogen red* and nuclei are blue.

Glycogen is soluble in water and alcohol solutions of less than 50 per cent. strength but not in trichloracetic acid and stronger alcohols.

Gage's Method.—Fix the tissues in 95 per cent. alcohol and embed in paraffin in the usual way. Cut sections and mount upon slides, flattening with the following (Lugol's) solution.

Iodin	1.5 gms.
Potassium iodid	3.0 gms.
Sodium chlorid	1.5 gms.
50 per cent. alcohol	300 c.c.

Cover the section with this solution, which acts as the stain, for five to ten minutes, then dehydrate, remove the paraffin with xylol and mount in melted vaselin. To make the preparation permanent ring with shellac. The *glycogen granules* are *mahogany red.*

Mast Cells.—Small pieces of tissue are placed in the following for twenty-four hours:

Formalin, 40 per cent.	100 c.c.
Alcohol, 90 per cent.	100 c.c.
Toluidin blue	6 gms.

Place for several hours in 70 per cent. alcohol, changing twice. Transfer to 96 per cent. alcohol for several hours, then absolute alcohol, benzol and paraffin. In the sections the *mast cells* are an *intense blue* and sharply outlined upon a pale blue background. This is also a selective stain for the chief cells of the rabbit's stomach.

Plasma Cells and Mast Cells.—Sections of tissues, preferably hardened in alcohol, are stained for fifteen minutes to twelve hours in polychrom methylene blue. Wash with water and decolorize with water containing a few drops of glycerin-ether for five to ten minutes. Wash well with water, dehydrate in absolute alcohol, clear with xylol and mount in balsam. The nuclei are blue and the *granules of the mast cells* are *red* while *those of the plasma cells are blue.*

Mitochondria, or **plasmosomes** are readily dissolved by acids and these must not be present in the fixatives used. For this reason Helly's fluid or Flemming's solution (eight days) in which the acetic acid has been reduced to only a few drops are best adapted to this technic. The paraffin sections should not be over 3μ to 6μ in thickness and should be stained by the iron-hematoxylin method. The *mitochondria* are seen in the form of black rods, filaments or granules while the other structures are grayish (Meves).

According to **Benda's method** fix for eight days in Flemming's solution, as above, and then wash in water for one hour. Then place in a mixture of equal parts of pyroligenous acid and 1 per cent. chromic acid for twenty-four hours. Transfer to a 2 per cent. solution of potassium bichromate for twenty-four hours. Then carry through paraffin infiltration as usual and make thin sections.

Mordant the sections in a 4 per cent. solution of ferric chlorid for twenty-four hours and rinse with water. Place then in a solution of Kahlbaum's sulphalizarinate of soda (1 c.c. of a saturated alcoholic solution of this salt in 100 c.c. of distilled water) for twenty-four hours.

Wash the sections and cover with crystal violet (saturated solution of crystal violet in 70 per cent. alcohol one part; 1 per cent. HCl in 70 per cent. alcohol one part; anilin water two parts); warm the sections until a steam is given off.

Wash with water and differentiate for a minute or two in a 30 per cent. solution of acetic acid, and then wash in running water for ten minutes.

Blot the water, dehydrate in absolute alcohol, clear with oil of bergamot followed by xylol and mount in balsam.

Chromaffin granules are readily fixed and stained by chromic acid and salts of chromium. As these granules are readily soluble in acids these must not be present in the fixative. Helly's fluid is one of the best for the fixation and staining of them especially as it permits of the use of various nuclear stains. The granules are stained a *light brown.*

CLEARING AGENTS FOR SECTIONS

After sections have been stained and dehydrated the alcohol must be removed by some agent that will permit of the use of a permanent mounting medium. There are several of these *dealcoholization* reagents, some answering better for some stains than others.

Creosote (Beechwood).—This oil clears readily and may be used with practically all stains. It has the advantage of not dissolving celloidin and is an excellent agent for general laboratory work. It clears in from three to five minutes.

Cedar oil clears tissues readily from 95 per cent. alcohol and does not extract anilin dyes.

Oil of origanum clears readily, celloidin is not affected but it removes anilin dyes somewhat. It is especially employed after picrofuchsin stain.

Clove oil acts rapidly but dissolves celloidin and removes anilin dyes. Sections become hard and brittle and yellow with age. It acts better when mixed with an equal part of oil of bergamot.

Oil of Bergamot does not extract anilin dyes nor does it dissolve celloidin. It will, however, remove eosin.

Xylol, toluol, benzol, all act very rapidly, and require dehydration with absolute alcohol. They are useful with anilin stains, and are readily applicable as solvents of balsam. They, however, render celloidin stiff and hard.

Carbol-xylol is a mixture of **xylol** and **carbolic acid.**

Xylol	3 parts.
Carbolic acid	1 part.

For larger sections, *i.e.*, brain stem, the writer prefers the following mixture:

Carbol-xylol	2 parts.
Clove oil	1 to 2 parts.

The clove oil keeps the celloidin soft and pliable so that upon blotting the sections are flat and not raised in ridges.

It acts very rapidly, and is best for hematoxylin and carmin stains; it does not stiffen celloidin.

Anilin oil-xylol consists of **anilin oil,** *two parts*, and **xylol,** *one part.* It is more commonly used than the carbol-xylol mixture.

Most of the oils require about *five minutes* to act. The sections are set aside during this time. In the case of rapidly acting agents, the slides are retained in the hand and rocked back and forth until the section is clear. This is usually accomplished in a minute or so.

MOUNTING MEDIA

After clearing, the sections are ready for the final step, that of **mounting.** There are a number of **mounting media,** such as **balsam, dammar, Farrant's solution, glycerin jelly** and **glycerin.**

The object of mounting is to make a permanent preparation. The choice of medium may depend upon the stain used. If this is no factor the chosen medium should have a refractive index as near crown glass as possible (1.518). Aqueous, glycerin and glycerin jelly mounts may be made nearly permanent by preventing evaporation. This is done by ringing as will be explained later.

Sections and tissues that cannot be dehydrated and cleared for special stain reasons are mounted in glycerin, syrup or gum.

Glycerin Media.—Glycerin is an excellent preserving medium. When diluted with water structures are more easily examined and studied than when mounted in pure glycerin, but they are not so well preserved. To preserve in pure glycerin it is best to place the object for a few hours in a few drops of glycerin-alcohol mixture (glycerin one, alcohol one, water two parts) so as to allow the gradual evaporation of the alcohol. It may then be covered with pure glycerin, or glycerin jelly and then sealed.

Glycerin jelly is a solid at ordinary temperatures and may be softened with heat and then poured upon the object that has been previously treated with glycerin and water. A drop is placed upon the specimen, and the cover-glass quickly applied, as this medium sets rapidly. It is used for special purposes, as for *isolated cells, urinary casts, crystals,* etc. Neither dehydration nor clearing is necessary.

Glucose Mixture.—Mix forty parts of glucose and ten parts of glycerin in 140 parts of water. Then add seventy parts of camphorated spirits and filter. This is especially used for mounting sections and objects stained with the anilin dyes as it preserves these colors. Evaporation may be prevented by ringing.

Gum and Syrup.—Dissolve picked gum arabic 50 grams, and cane sugar (not candied) 50 grams in 50 c.c. of distilled water over a water bath and add 0.5 gram of thymol. This sets quickly and gets as hard as balsam. It is used for mounting preparations stained with methylene blue.

Farrant's medium consists of 4 ounces of picked gum arabic, 4 ounces of water and 2 ounces of glycerin. Sections are covered with this, a cover-glass applied and later a cement ring is put on.

Resinous Media.—These media comprise gum sandarac, Canada balsam, gum dammar and colophonium. These are all solids and are liquefied by the action of certain volatile solvents.

Euparal is a new mounting and preserving medium. This is a mixture of camsal, sandarac, eucalyptol and paraldehyde. It is colorless or greenish, dries slowly and is considered better than balsam (Lee). The sections can be mounted directly from 95 per cent. alcohol without clearing, or, after dehydration, the sections may be treated with isobutylic, or propylic alcohol and then mounted in euparal.

Balsam.—Sections to be mounted in balsam must be thoroughly dehydrated and cleared in an oil. The oil is then removed by blotting, a small drop of balsam placed upon the specimen and a clean cover-glass applied.

The balsam is soluble in *chloroform*, *turpentine*, *benzol* or *xylol*. The latter agent is the best. Sections mounted in this medium are permanent.

Dammar is more complex. It consists of the following:

Gum dammar	1½ oz.
Gum mastic	½ oz.
Turpentine	2 oz.
Chloroform	2 oz.

The dammar is to be dissolved in the turpentine, and the mastic in the chloroform. Each is to be filtered, the filtrates mixed and the mixture filtered. This is to be kept in a well-stoppered bottle to prevent the evaporation of the chloroform.

Colophonium.—Pale colophonium is dissolved in pure turpentine to form a solution of medium consistency. This sets slowly and is injurious to alum hematein stains, but is excellent for methylene blue and other general stains.

After the sections are ready for mounting a drop or two of the selected mounting medium is placed upon the object and a clean cover-glass applied.

Cements.—Aqueous and glycerin mounts are rendered permanent by painting the clean edges of the cover-glass with a layer of glycerin jelly and repeating this several times, allowing each coat to set. This seals the cover-glass. This may be followed by a mixture of gold size one part, dammar two parts, dissolved in benzol. Several rings of this are applied at intervals of twenty-four hours.

Shellac cement for ringing may be made by dissolving shellac to the desired consistency in wood alcohol, or naphtha. Add 20 drops of castor oil to each ounce.

DECALCIFICATION

Bone and **teeth** may be ground for study. If sections are desired, the inorganic substance must be removed by means of acids. This process is **decalcification.**

Whole teeth and small pieces of bone are fixed and hardened in solutions containing a salt of chromium, and are allowed to remain as long as required. After being thoroughly washed and dehydrated as above, they are ready for the decalcifying agent, of which large quantities are to be used. The solutions given below are the most important.

Phloroglucin-nitric acid is no doubt the best. It consists of

Phloroglucm	1 gm.
Nitric acid (concentrated)	5 c.c.
Alcohol (70 per cent.)	100 c.c.

The phloroglucin is dissolved in the nitric acid, and allowed to stand until the fumes have disappeared (about twenty-four hours). The alcohol is then added, and then 5 to 10 per cent. of nitric acid. The teeth or bone are placed therein until readily penetrated by a needle or cut with a scalpel. The tissues are then transferred to alcohol and dehydrated in the manner already stated. Celloidin is the better infiltrating agent, as heat tends to harden osseous tissues. Additional nitric acid may be added from time to time as the solution weakens.

Mayer's solution is a 5 per cent. solution of nitric acid in 95 per cent. alcohol. It acts very well. The alcohol is supposed to prevent swelling of the tissues.

Trichloracetic Acid.—A 5 per cent. solution of this is used. It is slower than the nitric acid, but the treatment is the same.

Picric acid in a saturated aqueous solution is only adapted to small objects as young embryos and is a very slow reagent. It must be frequently renewed. **Picronitic** and **picrohydrochloric acids** act more rapidly.

Decalcification may be carried on after the tissues have been imbedded in celloidin. The celloidin block is transferred to a 10 to 40 per cent. solution of nitric acid in 85 per cent. alcohol and allowed to remain until decalcification is complete. Then the block is washed in 85 per cent. alcohol containing precipitated carbonate of calcium to neutralize the acid. The tissue is then ready to be mounted upon a wooded block and cut. This is an excellent method for the temporal bones of mammals.

GRINDING

Macerate a tooth or a piece of fresh bone to remove the fat and soft parts. Saw thin sections and cement them to a glass plate with sealing wax. Grind to one-half the thickness on a fine emery wheel. Unseal and reseal the ground side toward the plate and grind the section until quite thin. Remove the section carefully and rub upon a water hone to the desired thinness, then wash, dry thoroughly and mount in balsam.

Dry Method.—Cut sections one-sixteenth of an inch thick with a jeweler's saw. Place this section near the end of a microscope slide, heat some shellac just to the melting point and pour it around the section to form a zone about one-half inch wide. Be sure to press the section firmly against the slide while the shellac is setting so as to prevent any of this from getting under the section. The grinding is done upon sand, emery or carborundum papers according to the hardness of the substance to be ground. Sand paper Nos. 2, 1, 00 and 0000 are the best grades. Brittle substances grind best upon No. 00 using a light touch. Tougher substances should be started upon Nos. 2 and 1. During grinding the index finger of the hand holding the slide should be placed back of the section so as to insure uniform pressure to all parts of the section. The section should be moved in an elliptical manner and the paper kept free of the particles resulting from the grinding. When this surface is ground true it is finished upon No. 0000. *Polishing* is accomplished by rubbing the ground surface first upon the back of a piece of sandpaper, then upon a piece of smooth ground glass, upon the palm of the hand or upon a razor strop.

After gringing one surface the section is removed by first chipping the shellac away from the edge and then soaking the specimen in 95 per cent. alcohol or wood alcohol. When the shellac is softened the section may be lifted by slipping a safety razor blade under it and lightly lifting the section to another clean slide. The polished surface is then cemented to the glass as above. As the second grinding proceeds the section may be examined under the microscope from time to time until the desired thinness has been attained. As the section becomes thinner greater precaution must be taken in grinding. This surface is then finished as before. To remove the section place the slide horizontally in a Petri dish of 95 per cent. alcohol for four or five hours if necessary. The section may then be stained in the regular manner, or the section may be dried and mounted in balsam.

This method was devised by Dr. J. I. Fanz in the preparation of a hard and brittle plant stem where all other methods absolutely failed. The results of this method were exceptionally good and the method works equally well with bone, shell, etc.

INJECTION

Injection Masses.—In order to study the circulatory system, the vessels must be injected with a substance that will outline them. For this purpose, either an *aqueous solution of carmin* or *of Berlin blue*, or *gelatin masses* are used.

Berlin blue is used in water, one part to twenty, and this is injected with a *hand syringe* or by *continuous air pressure.* It gives very good results.

The gelatin masses may be either **carmin** or **Prussian blue**, or **Berlin blue.**

The **carmin mass** consists of the following:

Carmin	2 gms.
Water.	
Ammonia.	

Stir the carmin in a little water, and add strong ammonia, drop by drop, until the carmin is entirely dissolved. Filter the solution and add it carefully to the melted gelatin. The latter is prepared by soaking gelatin in double its quantity of water, and melting. The mixture is stirred and then neutralized with dilute acetic acid. If too acid, the carmin will be precipitated, and if the ammonia is not neutralized and the gelatin is quite alkaline, the stain will not be limited to the injected vessels, but will be diffused into the surrounding tissues.

This mass should be filtered while hot, and preserved with a little camphor.

The **Prussian blue** mass is somewhat similar. Four gms. of the Prussian blue are stirred into 80 c.c. of water, and the mixture added to gelatin prepared as above. The solution is filtered while hot, and preserved with camphor, or covered with methyl alcohol.

The entire body, or individual organs, may be injected. When the hand syringe is used, great care must be exercised that the pressure be not too great, as the vessels will rupture and the mass extravasate. The *continuous air pressure* method is the better. The mass must be melted and the animal kept warm by immersion in warm water. As soon as the injection is complete, the animal or organ is immersed in ice-water, so that the gelatin may set immediately. When the body is cooled, the organs are cut into blocks, and transferred to 80 *per cent. alcohol*, where they remain until thoroughly hardened, which takes from one to three days. The addition of 5 per cent. of formalin will hasten the hardening. They are then treated with 95 per cent. alcohol to dehydrate, then cleared and infiltrated like any other tissue.

White Mass.—Precipitate 125 to 185 c.c. of a cold saturated solution of barium chlorid by adding sulphuric acid drop by drop. Allow the precipitate to settle for twenty-four hours and decant the clear fluid. The remaining mucilaginous mass is mixed with an equal volume of strong gelatin solution.

Yellow Mass.—Mix equal volumes of concentrated gelatin solution and a 4 per cent. solution of silver nitrate and warm; add a small quantity of pyrogallic acid which reduces the silver rapidly. Then add 5 to 10 per cent, by volume, of glycerine and 2 per cent. by weight, of chloral in a concentrated solution and strain. This mass is yellow in the capillaries and brown in the larger vessels.

Self Injection of Living Animals.—This is accomplished by allowing a definite quantity of blood to escape from an opening in a vein of a living animal and replacing the lost blood by some innocuous coloring substance; in this way the contractions of the heart fills the vessels with much less injury than in the injection methods.

Dissolve 7.75 grams of carmin in 3.6 c.c. of ammonia and add 30 c.c. of distilled water. Filter. Remove 10 c.c. of blood from the jugular vein of a rabbit and then inject 10 c.c. of the above solution. If the larger vessels are then rapidly ligated, first the vein and then the artery, a physiological injection of the vessels will be obtained. The injection may also be accomplished by placing the above fluid in the stomach, rectum and abdominal cavity. After the injection has been accomplished the organs are placed in acidulated alcohol to cause the fixation of the carmin.

For *staining the tubules of the kidney* Heidenhain uses a cold saturated solution of either indigo blue sulphate or phenizine sulphate of sodium. Inject 25 to 50 c.c. of this into the vein of a medium sized rabbit or 50 to 75 c.c. into a medium sized dog. After the animal has passed blue urine for some time it is killed by bleeding and the coloring matter is fixed by injecting the kidney, with absolute alcohol, through the renal vessels.

Intravitam Injection.—Heat 1 gram of rectified methylene blue in 100 c.c. of normal salt solution; allow this to cool and then filter. Some of this may be injected into the vena cutanea magna of a living frog and the organs removed in one hour and treated as given below. Twenty c.c. of the solution may be injected, subcutaneously, into a young rabbit and repeated in one hour. At the end of two hours the animal may be killed and the nerve system removed. Organs may be injected with the same solution until they have a bluish color, then they are left undisturbed for one hour.

Place pieces of such tissue, not over 3 mm. in thickness, into a saturated aqueous solution of ammonium picrate for forty-five minutes. Transfer to a solution of ammonium molybdate (1 gram to 100 c.c. of water and 10 c.c. of a 0.5 per cent solution of osmic acid) for four to twelve hours. Wash thoroughly with water, dehydrate, clear in xylol and imbed in paraffin. Section.

Corrosion.—In order to study the normal cavities, the distribution and arrangement of ducts and blood-vessels in an organ, a special mass is injected and the soft parts removed, thereby leaving a cast of the system injected. The mass should fuse at a low temperature (water bath) and should not soften at the high temperature of the summer months. It should take color, readily, should harden rapidly and uniformly without cracking.

One of the best mixtures consists of ozokerite two parts, paraffin (45° to 50°C.) two parts and white wax one part. For coloring it is advisable to use the various oil colors put up in tubes. These are added slowly to the melted mass with constant stirring. The various colors are English vermilion, ultramarine blue, Prussian blue, purple lake, chrome green, chrome yellow, Chemnitz white, etc.

A solid metal syringe of sufficient capacity for each injection should be utilized and the canula should narrow abruptly at the point. The blood is removed from the organ by washing and milking the vessels and if fine injections are desired it is best to float the organ in warm water. As soon as the injection is completed the organs are cooled as rapidly as possible. They are then freed of any water in the vessels and placed in a dish and gradually surrounded with fuming commercial hydrochloric acid. At first a glass plate should cover the dish which should stand in the open air or under a chemical hood. The time required varies from several days to a week and as long as the acid fumes it may be used again. Remnants of the organ may be removed by cautiously washing the cast.

BLOOD TECHNIC

Blood is drawn from the finger tip or lobe of the ear. The part is thoroughly cleansed and finally washed with alcohol. A sterilized needle is then plunged to a depth of about one-eighth of an inch, and the blood allowed to flow. The part *should not be squeezed*, as this dilutes the blood with lymph, and causes errors in accurate work.

Blood spreads are obtained by touching a drop of blood with a cover-glass, and immediately placing this upon a second glass. The two are then *slid* apart, so that a *thin film* of blood is present upon each. If the glasses are *lifted* apart, the cells are greatly distorted and useless for study. A better way is to place a drop of blood upon one slide and then drag this drop across the slide with the short edge of another slide; this gives a more extensive and a more even spread.

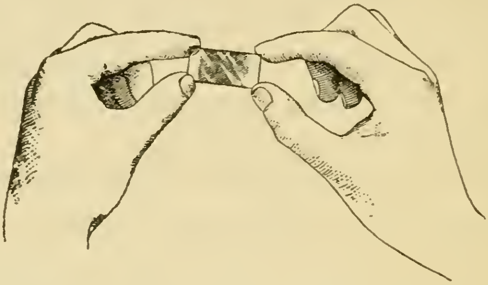

Fig. 4.—Drawing Apart the Cover-glass. (*Da Costa.*)

The spreads are allowed to dry in the air, and then fixed by (1) **heat**, (2) the **absolute alcohol-formalin solution**, or (3) **absolute alcohol-ether mixture.**

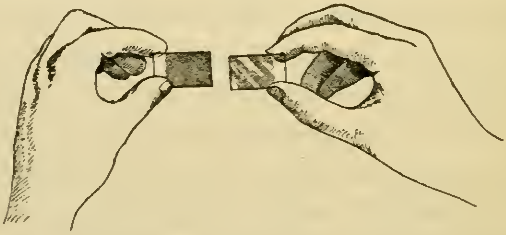

Fig. 5.—The Cover-glasses after Separation. (*Da Costa.*)

If **heat** is used, the spreads are placed in an oven, and kept at a temperature of 120°C. for twenty minutes. Ehrlich prefers this method.

The **alcohol-ether mixture** consists of *equal parts of absolute alcohol and ether.* This fixes the spreads in twenty minutes. Results with this fixative are very good.

The **alcohol-formalin mixture** consists of *nine parts of absolute* *alcohol* and *one part of formalin.* Spreads are fixed in twenty minutes.

After fixation, the spreads are allowed to dry, and may then be stained like any other tissue. Hematoxylin and eosin give a good result.

Among special stains is the **Ehrlich-Biondi-Heidenhain stain.** For its composition, see **stains,** p. 21.

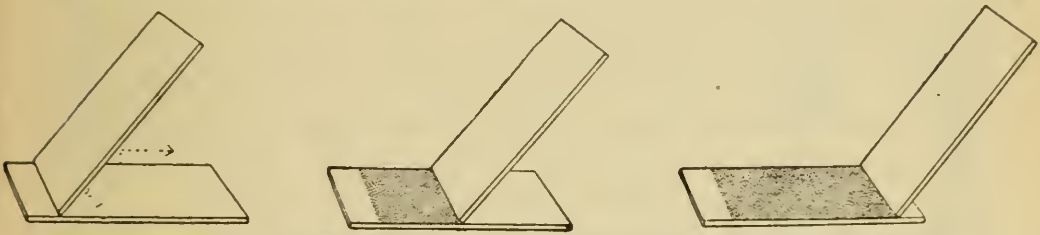

FIG. 6.—PREPARATION OF SMEARS WITH TWO GLASS SLIDES. (*Da Costa.*)

Wright's blood stain is one of the most satisfactory, and is prepared in the following manner:

Steam 1.5 grams of methylene blue in 150 c.c. of a 1 per cent. aqueous solution of sodium bicarbonate for one hour, in a sterilizer. Add a 1/10 per cent. aqueous solution of yellowish eosin to 100 c.c. of the methylene blue solution until the mixture turns purple, and a yellowish metallic scum forms upon the surface, and a blackish precipitate appears; about 500 c.c. of eosin solution will be required, and it should be added slowly, while constantly stirring. The solution is then filtered, the precipitate dried and made into a saturated solution with methyl alcohol. This solution is filtered and 80 c.c. of the filtrate are diluted with 20 c.c. of methyl alcohol.

Dried spreads are stained for one minute with this solution, and the stain then diluted upon the glass, with water, until the stain is semi-transparent. After two or three minutes, the spreads are thoroughly washed with distilled water, dried quickly and mounted. The acidophilic granules are reddish-lilac and red, while the basophilic granules are deep blue or even black.

This solution both *fixes* and *stains* the cells.

Leischman's stain is a modification of Wright's. It can be purchased in solid form and is very satisfactory.

Eosin and **methylene blue** give good results. The spreads are stained in a ½ per cent. alcoholic solution of eosin for two or three minutes, using gentle heat. Then they are placed in a saturated aqueous solution of methylene blue for two or three minutes. The spreads are then thoroughly washed, dried and mounted in balsam. As a rule, the granules of the leukocytes are well-stained.

In order to obtain the *bell-shaped red cells,* the finger should be thoroughly cleansed, and the blood drawn as usual. The first drop should be wiped off and a drop of 1 per cent. osmic acid solution placed over the puncture. The blood then flows into the osmic acid, which acts as a fixative, and prevents contact with the air until fixation is complete. If this drop be examined under the microscope, the bell-shaped cells will be seen in great numbers.

Blood platelets may also be stained in the above way.

Erythroblasts of the spleen may be studied in spreads made by drawing thin pieces of the organ over cover-glasses. These are then fixed in the following:

Mercuric chlorid	78 grs.
Sodium chlorid	28 grs.
Water	30 c.c.

This solution should be filtered, and spreads fixed in it for one minute. They should then be washed and stained one-half hour with aqueous hematoxylin, washed and covered with a 3 per cent. solution of eosin for two to three minutes. They are then washed, dried and mounted.

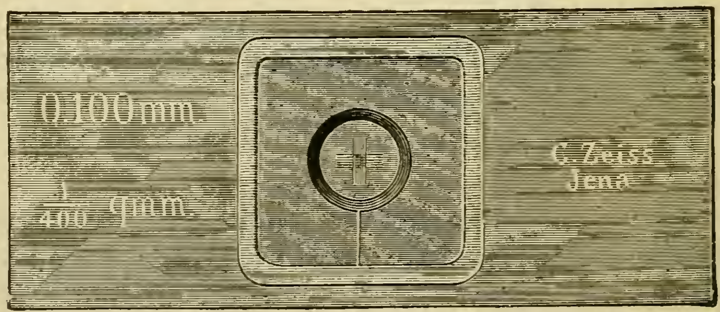

Fig. 7.—Thoma-Zeiss Counting Chamber.

Spreads may be stained for three minutes with eosin, and one-half minute with 5 per cent. methylene blue, then washed, dried and mounted.

To determine the number of blood-cells the **hemocytometer** is used. This consists of a *heavy glass slide*, a *heavy cover-glass* and *two pipets*. In the middle of the slide there is a small disc of glass upon which are marked 400 squares each side of which is 1/20 mm. in length, making 1/400 sq. mm. square surface for each square. Surrounding the disc is a glass ring that is 1/10 of a mm. higher than the disc so that when the heavy cover-glass is in place the cubic content over each small square is 1/4000 of a cu. mm.

The stem of the pipet for counting the red blood-cells is so graduated that it constitutes 1/100 of the cubic contents of the bulb portion; above the bulb is a mark 101. The blood to be examined is drawn to the mark 1 (just below the bulb) and then the diluting and staining fluid is drawn to the mark 101, giving, thus, a dilution of 100. The contents of the bulb are then thoroughly mixed by means of a small glass pearl in the bulb and the diluted blood is then ready to be examined. The pipet used for counting the white cells is constructed for a dilution of only ten times.

For the dilution of the blood the following solutions may be used:

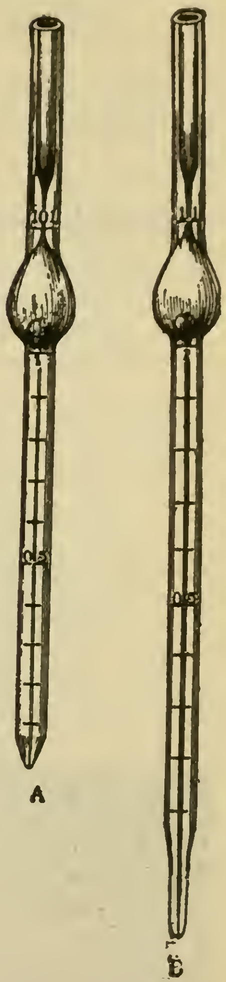

Fig. 8.—Thoma-Zeiss Capillary Pipets.

A, Erythrocytometer; B, Leucocytometer.

Toison's Fluid.

Methyl violet 5 B	0.025 gm.
Neutral glycerin	30.0 c.c.
Distilled water	80.0 c.c.

After mixing the methyl violet and the glycerin add the water and to this mixture add the following:

Sodium chlorid	1.0 gm.
Sodium sulphate	8.0 gms.
Distilled water	80.0 c.c.

After filtration the solution is ready for use. As the white cells are stained violet they may be counted at the same time as the red cells.

Hayem's Solution.

Bichlorid of mercury	0.5 gm.
Sodium chlorid	1.0 gm.
Sodium sulphate	5.0 gms.
Distilled water	200.0 c.c.

With this solution only the red cells are counted.

Sherrington's solution consists of the following:

Methylene blue	0.1
Sodium chlorid	1.2
Neutral potassium oxalate	1.2
Distilled water	300.0

After the blood has been drawn the first drop is wiped away and then from the next the blood is drawn up to the mark 1. The pipet is then put into the diluting fluid and this is drawn up to the mark 101 and the contents of the bulb thoroughly mixed. The contents of the stem of the pipette are then forced out and a small drop of the contents of the bulb is then placed upon the small disc of the glass slide and the cover-glass applied. The slide is then placed upon the stage of a microscope and then examined with a fifth inch (5 mm.), or long working distance one-sixth inch (4 mm.) objective. The red cells in at least 25 squares, but better in 100 squares, are counted and the total number divided by the number of squares counted. This gives the average content of one square. This number multi-

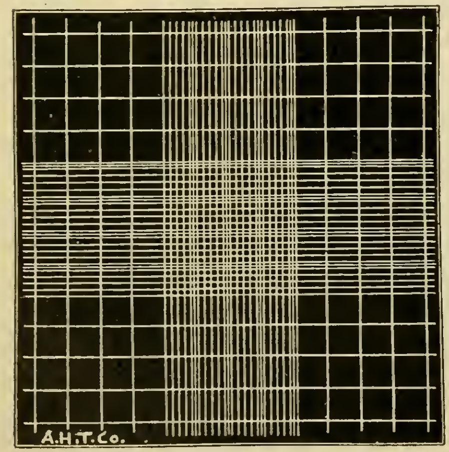

FIG. 9.—NEUBAUER RULING.

plied by the cubic content of a space (4000) and then by the dilution (100) will give the number of red cells per cubic millimeter.

$$\frac{4000\ \text{(cubic content of one space)} \times 100\ \text{(dilution)} \times n\ \text{(number of cells counted)}}{a\ \text{(number of squares counted)}} = \left\{\begin{array}{l}\text{the number of}\\ \text{red cells per}\\ \text{cu. mm.}\end{array}\right.$$

If the white cells are counted at the same time their number may be got in the same manner. If the white cells alone are to be examined then the 10 dilution pipet is used and the diluting fluid used is a ⅓ per cent. solution of acetic acid. By the use of this the red cells are bleached and the white cells are made more distinct. The same counting method is to be followed but the dilution is only 10, or the average number per square may be multiplied by 40,000 instead of by 400,000 as in the case of red cells.

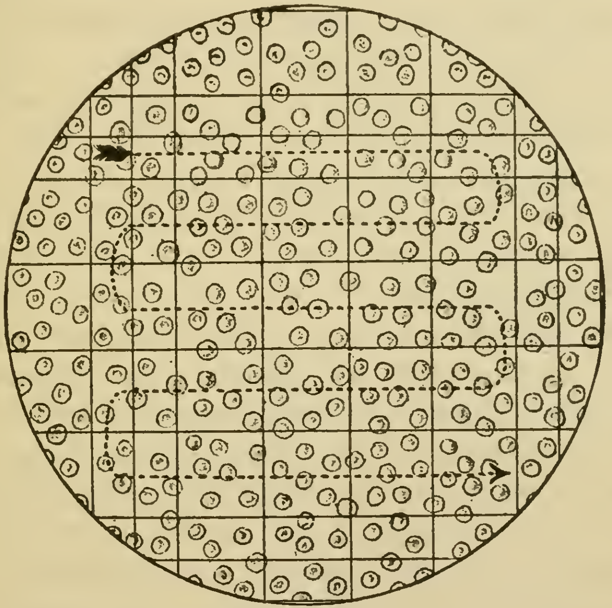

Fig. 10.—Plan of Counting the Erythrocytes. (*Da Costa.*)

The small squares are examined in the order indicated by the arrow, successive blocks of 25 squares being covered until the required number of cells has been counted.

The leukocytes may be counted at the same time as the red cell remembering that the dilution is 1 to 100.

In the *differential counting of leukocytes* at least 500 white cells should be counted. As each cell is noted it should be placed under its proper class and at the termination of the count the percentage of each variety may be readily obtained by dividing its number by 500. The count should be made with a 1/12-inch oil-immersion lens and the slide should be mounted in a mechanical stage and moved from side to side. In this manner the recounting of the cells in a given square is avoided.

Erythroblasts, if present, may also be counted and their number per cubic millimeter determined. The result is only approximate as it represents the ratio of the nucleated red cells to a definite number of leukocytes. The white cells are first counted, say 1000, and the number per cubic millimeter determined; then the number of nucleated red cells in the same area is estimated. The number of erythroblasts per cubic millimeter is then determined by multiplying the number of erythroblasts counted by the number of leukocytes per cubic millimeter and dividing by the number of leukocytes counted (1000). It is also usual to note whether the red cells are normoblasts, or megaloblasts and it is necessary to determine the ratio of these to each other.

The **blood platelets** are also estimated indirectly through their ratio to the erythrocytes. The blood to be examined is drawn directly into the diluting fluid (which is placed over the puncture). This is then thoroughly mixed and some is placed in the counting chamber of the hemocytometer. The number of red cells per cubic millimeter is then determined and a definite number in a certain area is counted. Then the number of thrombocytes in the same area is noted and the ratio or number per cubic millimeter is gotten in the same way as that of the nucleated red cells previously mentioned. The average is usually 1 platelet for each 22 erythrocytes.

Determann prefers the following diluting fluids for estimating the number of thrombocytes:

9 per cent. aqueous solution of sodium chlorid, methyl violet sufficient to impart a color; or

Sodium chlorid	1 gm.
Potassium bichromate	5 gms.
Distilled water	100 c.c.

Methyl violet sufficient to impart a color.

Toisson's or Sherrington's solutions may also be used.

The estimation of the red and white cells in *dried film preparations* is said to give more accurate results than the hemocytometer method. The cells are counted separately and tabloid stains are employed; that for the leukocytes consists of 0.25 gram of sodium chlorid and 0.004 gram of methyl violet; that for the erythrocytes consists of 0.25 gram of sodium chlorid and 0.0025 gram of eosin. One of each of these tablets is dissolved in 30 c.c. of distilled water and 0.5 c.c. of formalin is added to each and the mixtures are then filtered.

For *counting the white cells* 5 cu. mm. of blood is drawn into a graduated pipet and then mixed with 495 cu. mm. of the methyl violet diluting fluid (giving a dilution of 1 to 100) and thoroughly stirred. Then 5 cu. mm. of this mixture are drawn into a pipet and then placed upon a slide so as to cover an area about 10 to 12 mm. in diameter. This is allowed to dry and then balsam and a cover-glass are applied. The preparation is then examined under a 1.9 mm. lens (using a mechanical stage) and all of the leukocytes in the film are counted. The number of leukocytes counted multiplied by 20 will give the number of leukocytes per cubic millimeter.

In *estimating the erythrocytes* 5 cu. mm. of the *above mixture* for examining the leukocytes are added to 995 cu. mm. of the eosin mixture; this gives a dilution of 1 to 20,000. After mixing and allowing the red cells to stain for a few minutes 5 cu. mm. of this mixture are then placed upon a slide and allowed to dry as previously. The preparation is then covered with balsam and a cover-glass is applied. All of the erythrocytes in the film are counted and this number multiplied by 4000, the result is the number of red cells per cubic millimeter.

The *percentage of hemoglobin* in the blood is determined by means of an **hemoglobinometer,** or **hemometer.** There are quite a few of these instruments but only Dare' and von Fleischl's will be described here.

The **Dare hemometer** consists of a *hard rubber case* containing a *tapering graduated semicircle of glass* tinted with golden purple of Cassius. This is attached to a disc and scale so that the glass can be revolved and the scale read (from the outside). The scale gives percentages from 10 to 120. A *capillary blood chamber* belonging to the apparatus consists of two plates of polished glass; of these the one toward the light consists of opaque glass while the other is transparent. When these two are mounted a shallow space for the blood exists between them. The *eye-piece* and *tube* cover two openings, one back of the capillary chamber and the other back of the tinted graduated color standard. The section view gives the principle of the instrument. *J* represents the candle; *O* and *P* represent the two plates of the capillary chamber; *L* and *K* represent

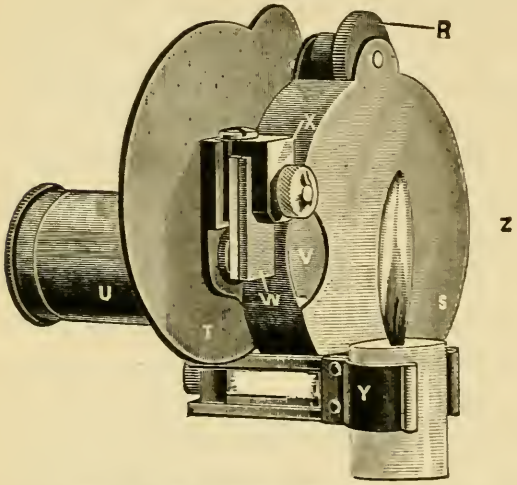

FIG. 11.—HEMOGLOBINOMETER OF DARE.

R, milled wheel; *S*, case inclosing the color disc; *T*, movable wing, which is swung outward; *U*, telescoping camera; *V*, aperture admitting light; *W*, capillary blood pipet; *Y*, detachable candle holder; *Z*, slot through which the percentage of hemoglobin is read.

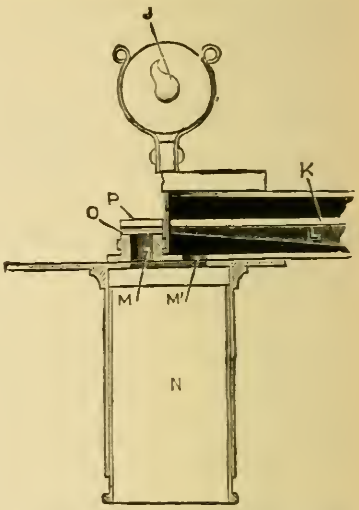

FIG. 12.—HORIZONTAL SECTION OF DARE'S HEMOGLOBINOMETER. (*Da Costa.*)

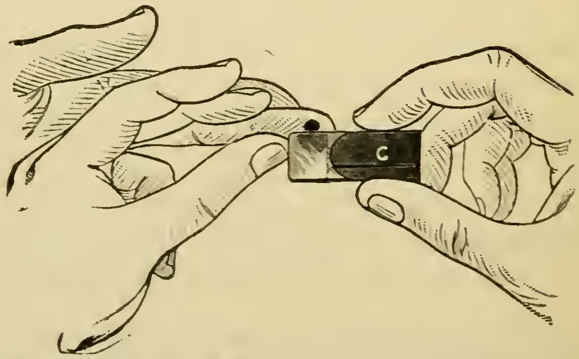

FIG. 13.—METHOD OF FILLING THE DARE BLOOD PIPET. (*Da Costa.*)

the color standard and glass disc; *M* and *M′* are the openings communicating with the capillary chamber and the disc chamber; *N* is the tube containing the eye-piece.

In using the apparatus the capillary chamber is filled by touching its edge to the drop of drawn blood and then wiping the excess off. It is then placed in position in the apparatus and the candle is lighted. The instrument is then held to the eye toward a dark wall and the disc revolved until the colors coincide, making sharp quick turns of the milled wheel. The capillary chamber should be taken apart and the plates thoroughly cleaned with water and acid alcohol after each use. J. C. Da Costa considers this instrument the most accurate, simple and convenient for clinical purposes. It has the especial advantages of not requiring a dark room and of using *undiluted blood.*

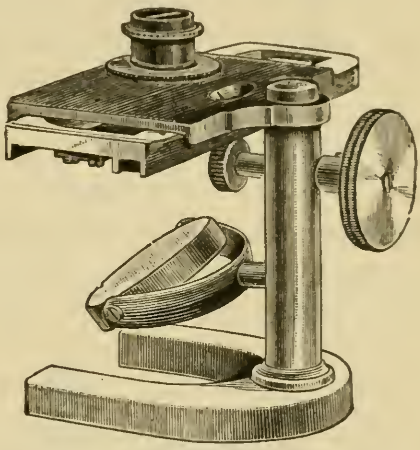

FIG. 14.—FLEISCHL'S HEMOMETER. (*Da Costa.*)

The **Von Fleischl hemometer** consists of a *stand* upon which is mounted a *movable wedge-shaped piece of tinted glass* (golden purple of Cassius). Upon the upright of the stand there is mounted a *disc of plaster of Paris* that is used to reflect the light through the diluted blood and color scale. In the center of the stage of the stand there is an opening to accommodate the mixing chamber. The *mixing chamber* is a short cylinder (with a glass bottom) that is divided into two compartments by a metal partition. When properly mounted one compartment overlies the wedge of tinted glass and the other contains the diluted blood and receives the light directly from the reflecting disc. The capillary pipet is of such a capacity that one pipetful of normal blood diluted

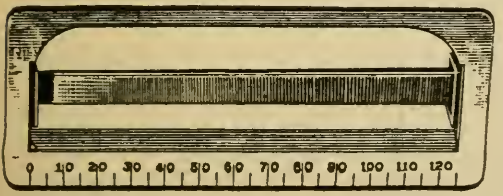

FIG. 15.—COLORED GLASS WEDGE OF FLEISCHL'S HEMOMETER. (*Da Costa.*)

with one compartment full of water will give a color that will correspond with that of the tinted scale opposite the mark 100.

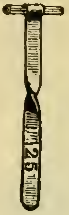

Fig. 16.—Pipet of Fleischl's Hemometer.

In making the test fill each compartment about one-quarter with distilled water. Then draw a fine needle and thread through the capillary pipet to clean it and then apply the pipet horizontally to the drop of blood drawn from the puncture. Wipe the outside of the pipet clean being careful that the pipet is exactly full. Then wash the blood into the compartment that is not over the colored scale; this is done by the use of a fine-pointed pipet and the capillary pipet is repeatedly rinsed. Stir the diluted blood with the handle of the capillary pipet until evenly mixed, rinse the handle into the compartment and add water cautiously until the compartment is level full. Then fill the compartment over the colored scale with distilled water until exactly full taking care that no water falls

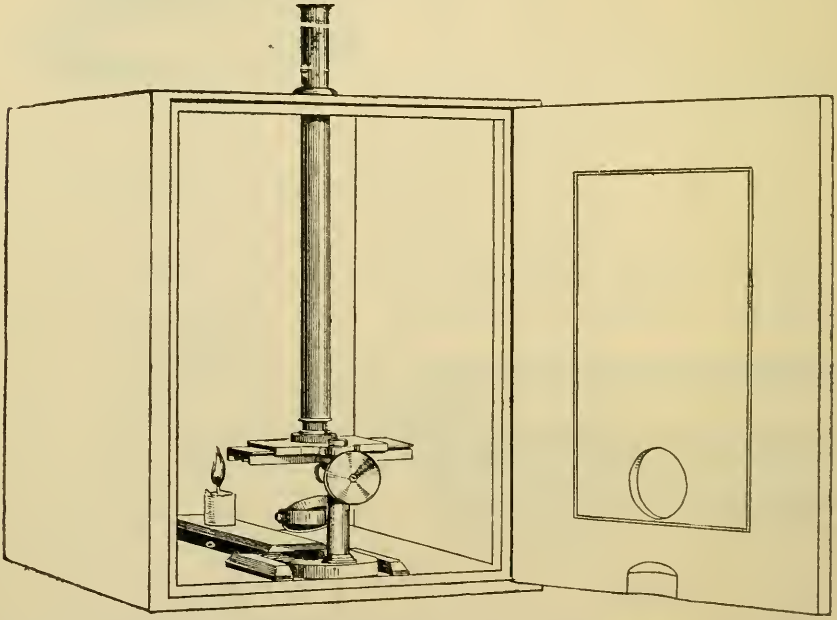

Fig. 17.—Light-proof Box for the Von Fleischl Hemometer. (*Da Costa.*)
The door of the box is closed and the color comparison made through the camera tube.

upon the thin partition as this will cause a diffusion between the two compartments and change the result. If the blood solution is turbid, due to the presence of fat, a little ether will clear it. The instrument is then placed in the lightproof box, containing a lighted candle; the lid is closed and the operator then stands at one end of the glass scaled and rotates the milled wheel with short and rapid turns. The start should be made at the dark end of the scale and this should be rapidly moved until the colors nearly coincide. After a short rest the colors are made to coincide. If the hemoglobin is 30 per cent. or under it is best to use two or three pipets of blood and then divide the result by two or three as the case may be. It is said that with the best of care an error of 5° may occur on account of the large field of the mixing chamber. To obviate this a mental diaphragm with a slit about one-eighth of an inch in width is placed under the glass bottom of the mixing chamber so that the slit is at a right angle to the partition. This cuts down the field to about 2.5° of the glass scale and thus greatly reduces the error.

Slide Technic.—The preparation of sections for microscopic study requires skill and care.

Paraffin sections are made to adhere to the slide by means of **Mayer's albumen.** This is prepared by mixing thoroughly *white of egg* and *glycerin* in equal parts and filtering. To the filtrate add 1 gram of sodium salicylate. A very thin film is all that is necessary.

The following desk reagents are sufficient for all ordinary work:

Coplin staining jar, containing *Iodin.*
Coplin staining jar, containing *Kerosene,* or *Xylol.*
Coplin staining jars, containing *Alcohol. Nos.* 1 *and* 2.
One Barnes bottle, containing *Hematoxylin.*
One Barnes bottle, containing *van Gieson's stain.*
One Barnes bottle, containing *Eosin.*
One Barnes bottle, containing *Alcohol.*
One Barnes bottle, containing *Water.*
One Barnes bottle, containing *Acid Alcohol.*
One Barnes bottle, containing *Creosote.*
One Barnes bottle, containing *Albumen.*
One Barnes bottle, containing *Picric Acid.*

The method of procedure for staining is given in detail below:

1. Cover a clean slide with a thin film of *albumen*.

2. Add a few drops of water, and upon this float the cut paraffin section.

3. Warm gently over a flame, so as to spread the section, but be careful *not to melt the paraffin*.

4. Drain and set aside, or in an oven, for six to twenty-four hours. The slide must be perfectly dry before the other steps can be carried out. Put an identification label on the slide.

5. Place in the *kerosene* for five to fifteen minutes, to remove the paraffin. Xylol may be used.

6. Wash with alcohol, to remove the kerosene, and place in the jar of *iodin*, five to ten minutes, *to remove the crystals of bichlorid* of the fixing agent.

7. Remove the excess iodin from the slide with tissue paper, wash with alcohol and place in the *first alcohol* jar for fifteen minutes, to remove the remainder of the iodin. This may be hastened by the addition of a little potassium iodid to the alcohol.

If a bichlorid fixative has not been used steps 6 and 7 may be omitted.

8. Drain the section, wash with water, cover with *hematoxylin* for three to five minutes, and wash with water to deepen the color.

9. **Counter-stain.**—*Eosin* one to two minutes, wash with water to remove excess stain and then alcohol; or,

Van Gieson one to one and one-half minutes, wash with water and then alcohol, as above; or,

Picric acid fifteen seconds and wash with alcohol.

Carmin may be used alone for fifteen minutes, or followed by picric acid, as in the preceding. If carmin is used alone wash the excess off with water and then cover with acid alcohol to *differentiate*. When the color becomes a brick-red, wash the acid alcohol off quickly with ordinary 95 per cent. alcohol and dehydrate in the usual way. Hold the slide in the hand while differentiating.

10. After washing with alcohol, *dehydrate* in the *second jar of alcohol*. Allow sections to remain about five minutes.

11. Clean the slide carefully *without allowing the section to dry*. Blot with tissue-paper.

12. Cover with a drop or two of *creosote for five minutes.* This removes the alcohol, renders the specimen transparent, and allows the use of balsam. This is *section clearing.*

13. Drain off the creosote, *blot*, add a drop of *balsam* and cover with a *clean* cover-glass.

14. Remove the identification label, apply a clean one, and write the name of the section thereon.

After the paraffin has been removed, the specimen should *never be allowed to dry.*

The above technic will answer for all ordinary histologic and pathologic work, and, if strictly adhered to, there will not be the slightest trouble in making excellent preparations.

CHAPTER II

THE CELL AND ITS PROPERTIES

Histology is the science that treats of the minute structure of normal tissues and organs. Although to the naked eye tissues may have an apparent structure that seems ultimate, when examined under the microscope this structure is seen to be but gross. Each section studied will be found to be composed of minute *elements*, more or less regular, and definitely grouped and arranged. These elements are **cells.**

Protoplasm is a viscid substance of neutral reaction and is essentially a colloidal substance. It consists, chemically, of (*a*) water that constitutes two-thirds of its weight; (*b*) inorganic substances as salts of calcium, potassium, sodium, chlorin, phosphorus and oxygen (free or in combination); (*c*) organic salts of usually phosphorus and iron, in the form of proteins and nucleoproteins. In addition certain nonprotein substances as lecithin and cholesterin are essential components of protoplasm.

Physically the cytoplasm consists of *colloids* and *crystalloids* held in suspension by the water. The *colloids* are present in two conditions (1) liquid or *sol* and (2) semi-solid or *gel*. The crystalloids are (1) *electrolytes* (bases, acids and salts) and, (2) *nonelectrolytes* (urea, sugar). There is no sharp line between colloids and crystalloids. As the fluidity of protoplasm is due to water and as protoplasm is sol it is usually called *hydrosol*. When, however, it is converted into the semi-solid or gel state it is referred to as *hydrogel*. This changing from the one to the other is constantly going on in the living cells and should an irreversible hydrogel be formed then life tends to cease.

Living protoplasm in structure is a granular gel. Kite considers it an *emulsoid* of which the colloidal particles are the structural units. It is a viscous hydrogel, apparently homogeneous, in which are granules of denser gels and liquid globules. Spindle fibers seem to be definite and distinct comparatively rigid threads. The nuclear granules and network he regards as denser masses of nuclear gel that gradually grade into the diluter gel of the achromatin.

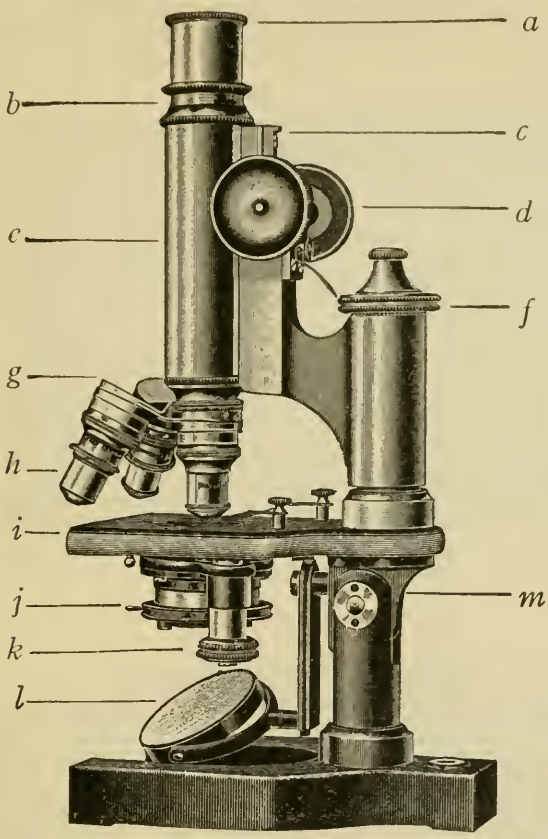

FIG. 18.—MICROSCOPE SUITABLE FOR GENERAL WORK.

a. Ocular or eye-piece; *b*, draw-tube; *c*, rack; *d*, milled head of pinion moving the rack; the rack and pinion (*c* and *d*) together are called the coarse adjustment; *e*, microscopic tube; *f*, micrometer screw by which the fine adjustment is operated; *g*, triple nose-piece or revolver which receives the objectives, *h;* in the above instrument there are three objectives which in turn may be rotated into the optical axis; *i*, stage on the upper surface of which are clips for holding the slide during examination; *j*, iris diaphragm in substage condenser; the diaphragm permits variation in the quantity of light admitted, and the condenser properly focuses the rays on the object examined; *k*, screw for raising and lowering the condenser by which the latter, when not in use, may be thrown to the side; *l*, mirror for reflecting light into the optical axis of the intrument; *m*, inclination joint permitting inclination of the instrument. The vertical column below the inclination joint is called the pillar and is solidly joined to the large, heavy, horseshoe base supporting the instrument.

A **cell** is a small mass of protoplasm containing a nucleus. It is the histologic basis of the body, and has a complex structure. Certain parts are absolutely essential for the proper peformance of its various functions, while others are accessories, which most cells possess. The parts of a typic cell are:

1. **Cell-body.**
2. **Nucleus.**
3. **Centrosome.**
4. **Nucleolus.**
5. **Cell-wall.**

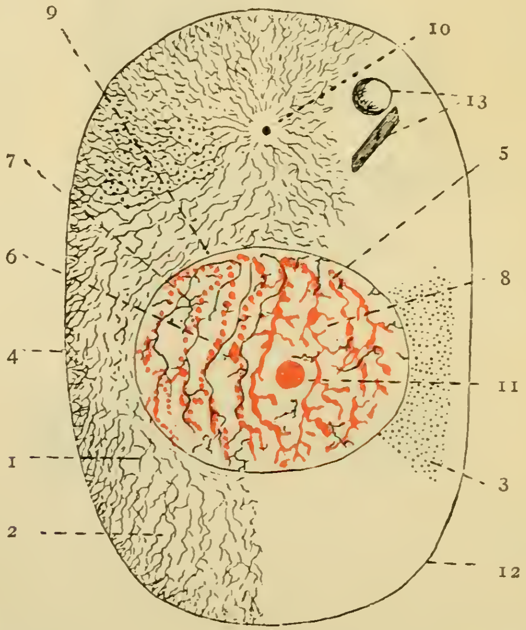

FIG. 19.—SCHEME OF A CELL.—Microsomes and spongioplasm only partly sketched. (*Stöhr's Histology.*)

1, Spongioplasm; 2, hyaloplasm; 3, microsomes; 4, exoplasm; 5, chromatin; 6, achromatin; 7, linin; 8, chromatic knots; 9, nuclear membranes; 10, centrosome; 11, nucleolus; 12, cell-membrane; 13, inclusions.

1. The **cytoplasm** or **cell-body,** may or may not be limited by a cell-wall and, in fixed cells, it consists of two main parts, the *spongioplasm*, or *filar mass* and the *hyaloplasm*, or *interfilar mass*.

The **spongioplasm,** as its name indicates, is a framework of comparatively solid structure, in the meshes of which is found the semi-fluid **hyaloplasm** or **paraplasm.** The elasticity of the spongioplasm is said to give rise to ameboid movements.

In the cytoplasm are to be seen small darkly staining bodies, the **microsomes** and paler masses, the **plastids.** At the outer margin of the cell-body is a narrow, peripheral zone, containing no microsomes, known as **exoplasm.** At times there are other structures present, as *fat globules, glycogen, secretion granules, vacuoles, pigment,*

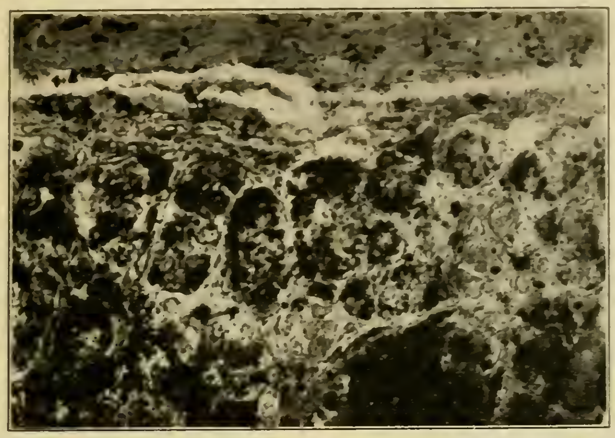

FIG. 20.—FAT GLOBULES IN THE CELLS OF THE ZONA GLOMERULOSA OF THE ADRENAL GLAND FIXED IN OSMIC ACID. (Photograph. Obj. 16 mm., oc. 10 ×.)

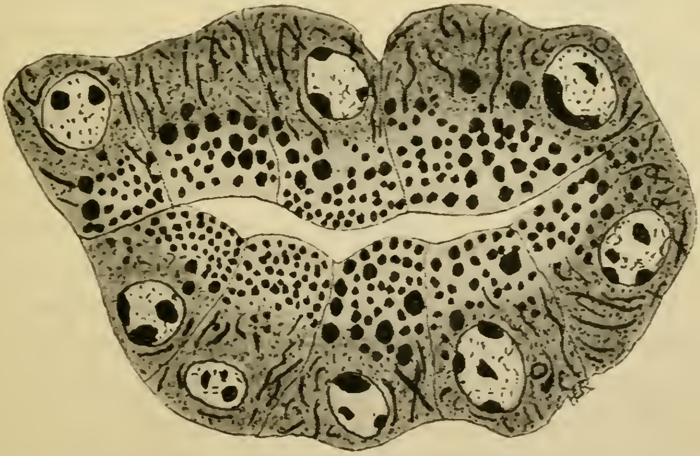

FIG. 21.—A SECTION OF AN ACINUS OF THE PANCREAS OF A GUINEA-PIG. The zymogen granules are in the lumen end of the cell while the mitochondria are basally disposed. (*After Bensley.*)

crystals, waste products, as *creatin, creatinin, urea, urates*, etc. These nonprotein substances constitute paraplasm.

The *granules* may be diffusely scattered or collected into groups and are probably formed under the influence of the nucleus. These vary in size and number in the same cell and different cells. They may be almost ultramicroscopic or large as seen in nerve cells (tigroid bodies). In glandular cells they can be seen gradually increasing in size as the elaboration of the secretion, with which they are connected, is progressing. They respond to different stains in the different cells; some granules are *eosinophilic*, others *basophilic* and still others *neutrophilic*. This is especially distinct in the different types of leukocytes. As regards the functions of granules some are *secretory*, as in glandular cells, and others are *nutritive*, as in nerve cells. These granules seem to be formed under the influence of the nucleus.

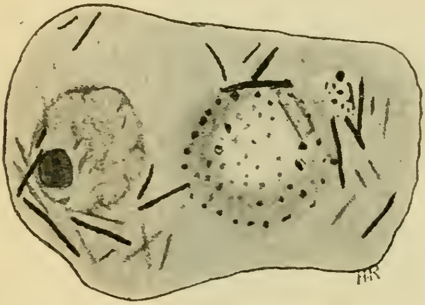

FIG. 22.—INTERSTITIAL CELLS OF THE HUMAN TESTIS SHOWING MITOCHONDRIA OF THE GRANULAR AND FILAMENTOUS FORMS. (*After Winniwarter.*)

Some granules seem to form contractile fibrils, which stain distinctly and are called **mitochondria**; these fibrils sometimes form spherical masses called *chondromitomes*. Mitochondria seem to be related to the metabolic activities of the cell, the formation of presecretion and excretion granules and the formation of fibrillæ in muscle fibers. Meves believes that the mitochondria share with the chromosomes the transmission of hereditary characters and others that they represent the region of and assist in oxidation processes. In the germ cells the mitochondria are of a granular form while in the somatic cells they are filaments or rods. They are found in all types of cells, in living plant cells and in animal cells grown in artificial media. In the latter instance they were studied by W. H. and M. R. Lewis who found that they changed shape, divided into granules and reunited into filaments. In fixed material they seem to be lipoid precipitation products having a chemical composition of lipoid (phosphatid).

In many nerve and glandular cells (stomach, liver) is seen a fine network of anastomosing channels, or *secretory capillaries,* called **trophospongium.** These are supposed to be connected with the circulation of nutritive material or secretion products. These may conduct the secretion to the ducts, or to the lymph or blood-vessels. In the two latter instances the secretion would be called *internal.* Holmgren believes that these channels have definite openings upon the surface of the cell while v. Bergen states that these canaliculi are not permanent but come and go.

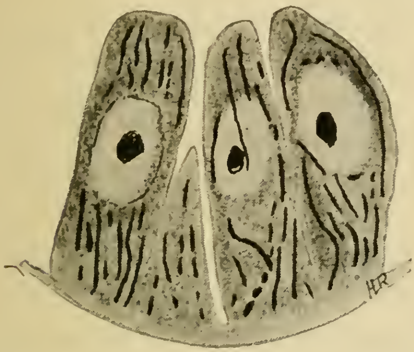

Fig. 23.—Intestinal Cells of the Rainbow Trout Showing Mitochondria. (*After Jordan and Ferguson.*)

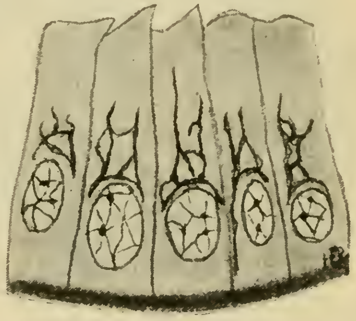

Fig. 24.—Intracellular Canaliculi. (*After Holmgren.*)

Fibrils are noted in various cells. In nerve cells they form a network and are called *neurofibrils;* in muscle cells they are parallel to one another and are the *muscle fibrillæ.*

The cell-body has affinity for *acid,* or *protoplasmic,* stains, such as *eosin, picric acid, carmin, orange, etc.*

2. The **nucleus** is usually a darkly staining, refractile body having a sharp outline, and occupying, as a rule, a central position. It controls metabolic activities and in cell division transmits characteristic features (heredity). In glandular cell, its location varies with the stage of secretory activity. Its structure resembles that of the cytoplasm, to a certain extent. The nucleus consists of a network and semi-fluid substance, surrounded by a distinct **membrane** or **wall.** The network is called the **chromatin,** or **nuclear fibrils,** and the semi-solid substance, the **nuclear matrix, sap** or **achromatin.**

Chromatin or **karyotome** is the part of the nucleus that responds to the stains. It is arranged as an irregular network of anastomosing fibrils, each consisting of a delicate central thread, the *linin*, upon which the real chromatin substance is arranged, in the form of granules (*chromioles*). Where the chromatin threads cross each other large masses of chromatin at times are seen; these are called *karyosomes*. It is the most important portion of the nucleus during the process of cell-division. In glandular cells the chromatin increases during the earlier stages of secretory activity and decreases during the later stages. The diminution probably represents the formation of special secretion products. During cell division the chromatin separates into a number of rod-like structures (*chromosomes*) that are of the same size and constant in number for the same species of animal, in each nucleus. Each chromosome consists of chromioles and both are capable of growth and of multiplication by division.

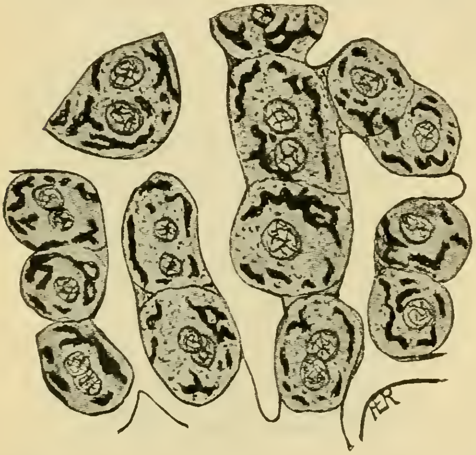

FIG. 25.—INTRACELLULAR CANALICULI OF THE LIVER CELLS COMMUNICATING WITH THE SINUSOIDS. (*After Schäfer.*)

Chromatin consists of nucleic acid combined with protein and has an affinity for basichromatic stains. The *linin* is *mucoid* in nature, contractile and oxyphilic in reaction.

The **achromatin** or **karyoplasm** is a semi-fluid substance that fills in the meshes of the chromatin. In the living condition it is apparently structureless but when fixed and stained it exhibits little granules that respond to the plasmatic dyes, called *oxychromioles*.

The **nuclear membrane** is that wall that sharply outlines the nucleus. It is present in all nuclei and is solid. Upon its inner surface it is connected with the chromatin network. It consists of *amphipyrenin* (basichromatin and linin) and responds to basichromatic dyes.

Of the above structures, the chromatin persists throughout all the stages of reproduction, while the remainder of the nuclear constituents disappear.

The nucleus responds to *nuclear stains* as *hematoxylin* and *basic anilin* dyes.

3. The **centrosome** is a small darkly staining structure, which, owing to its small size, has been found in but few of the cells of the human body. It is readily seen and studied in the ova of some of the lower animals, especially those of *ascaris megalocephala.* It lies, usually, just outside of the nucleus, in a small clear field called the **attraction sphere,** within which are seen delicate lines that radiate from the centrosome. The attraction sphere and the centrosome constitute the **astrosphere,** usually less than 1μ in diameter. In many gland cells the centrosome lies where the secretion accumulates. In intestinal epithelium that sends out pseudopodia it lies at the point of origin of these processes. It is occasionally divided constituting then a **diplosome.** In cells possessing multiple or lobulated nuclei the centriole usually consists of a group of particles (giant-cells of bone-marrow).

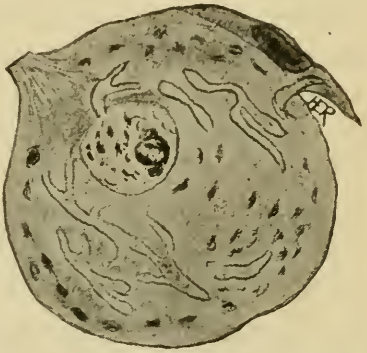

Fig. 26.—Trophospongium within a Ganglion Cell. (*After Holmgren.*)

Besides starting *cell-division,* the centrosome seems to play an important part during the resting stage. In pigment cells and white blood-corpuscles, it seems to preside over the movements of the whole cell, and in ciliated and flagellated cells over the action of these processes. It responds to the *iron-hematoxylin stain.*

4. The **nucleolus** or **plasmosome** is a small, oxyphilic body found within the nucleus. It is not always present, and more than one may be found. In nerve cells and ova it is unusually large and readily stained, while in others it is scarcely noticeable. It is probably the result of nuclear activity and at times parts of the nucleoli are passed into the cytoplasm. Some say that these particles are formed into secretion granules and others claim that they represent effete material. Its importance is doubtful, although it is now believed to be concerned in the formation of the central spindle during

cell-division. It consists of *pyrenin*, disappears during cell-division and is considered by some the seat of basichromatin formation. This is utilized by the chromosomes.

5. The **cell-wall** is a more or less prominent membrane that limits cells. It is not present in all animal cells, though all cells possess a delicate membrane that is solid and of a lipoid nature. In some instances, it consists of the differentiated, peripheral cytoplasm, and in others, is a secretory product of the cytoplasm. When a well-defined wall surrounds the entire cell it is called a *pellicula* (seldom used); if it is found upon the exposed surface, as in the intestinal cells, it is termed a *cuticular border*.

Of the above structures, the **cytoplasm, nucleus** and **centrosome** are the essential parts, when the important functions of the cell are considered. In red blood-cells the nucleus is absent, and, as a consequence, these cells cannot reproduce themselves.

Cells differ greatly in form and size from 4μ to 80μ; the nucleus conforms somewhat to the shape of the cell. The lobulated nucleus of the leukocyte is a peculiar modification of this general rule. Usually but one nucleus is present, but in giant cells and voluntary striated muscle, many are to be found.

Cells may fuse so as to form a single mass of protoplasm with nuclei at fairly regular intervals. This is called a **syncytium.** This term has also been applied to striated muscle tissue on account of the large number of nuclei present.

The cell, like the organism, exhibits a number of properties, such as **metabolism, growth, motion, irritability** and **reproduction.**

Metabolism is the sum of all of the changes that take place in a cell during the performance of its functions. The metabolic processes are controlled by the nucleus. The changes are chemical in nature and are increased by warmth and electrical stimuli. When the result is the formation of complex structures, the process is called anabolism; if destructive, the conversion of complex to simple compounds, the phenomenon is termed katabolism. **Secretion** and **excretion** are anabolic changes, as simple structures are converted into complex compounds. Secretion may be glandular secretion, or simply an intercellular substance may be formed.

Growth is the result of an anabolic process. The cells increase in size, equally or more often unequally, depending upon the organ. When the latter occurs, the cell-form is changed. By such a change in all cells, the organism increases in size, though the amount contributed by each cell may be microscopic.

Motion.—Cells exhibit the phenomenon of movement under three forms: **protoplasmic, ameboid** and **ciliary.**

Protoplasmic movement is difficult of observation on account of the slowness of the process. It has been demonstrated in a few animal cells but in plant cells it is easily observed, the streaming of the cytoplasm being an example (cyclosis). All animal cells are believed to possess it to a greater or lesser degree. It is made manifest by the changes in the form of the cytoplasm, by movements of the microsomes and by the changes in the position of the nucleus.

Ameboid movement is similar to that exhibited by the unicellular animal, the ameba. Nearly all animal cells possess it to some extent, it being well marked in especially a few cells, viz., the leukocytes, lymph cells and wandering connective-tissue cells. If a living leukocyte be studied under the microscope it will be seen to change continually in form. Gradually a bud-like process of the protoplasm will push out from one point or several may start from different points. These *pseudopodia* may retract or be extended for a considerable distance, the remainder of the cytoplasm flowing into one. Other pseudopodia are given off and the process is repeated. These processes may be either massive or *lobed*, or fine and *spine-like.* By this means the cell will gradually crawl across the field of the microscope. It is by means of this ameboid movement that leukocytes pass through the walls of the capillaries (*diapedesis*) and wander through the spaces of the tissues and organs or between other cells. This phenomenon is also exhibited when an ameboid cell takes in foreign particles, *i.e.*, ingestion of food, or when phagocytes attack bacteria or tissues.

Ciliary motion is limited to only a portion of the cell, that is, to delicate hair-like processes called *cilia.* In true ciliated cells it is said that a darkly staining body (presumably centrosomic in origin) is to be found at the central end of each cilium. The spermium moves by the action of its tail, a flagelloid structure.

One of the most characteristic examples of motion is exhibited by the muscles, especially the voluntary striated variety; here although the whole cell moves, the motion is limited to one direction. This is parallel to the long axis of the fibers and constitutes *contraction.*

Irritability is the property that cells have of responding to external stimuli. This property is exhibited best in the unicellular animals and others that possess no nerve system. In these forms it is a primary change in the cell. These stimuli, although almost innumerable, may, in a general manner, be grouped as *mechanical, electrical* and *chemical* in their nature, or due to *heat* or *light.*

All cells do not respond in the same manner to the same stimulus, nor do all stimuli cause the same reaction in an individual cell. The response of a cell to a specific stimulus depends upon its structure. Some, those of the organ of vision for example, respond to light only, while others may respond to one or more stimuli.

Under **mechanical stimuli** are *pressure, violent shaking* and *crushing,* any one of which will cause cells to respond in some manner.

While **heat** is a necessary condition for the activities of a cell it must be confined within rather fixed limits, these varying considerably, however, for different cells. If the temperature be raised to 40°C. (104°F.) the vitality of the cell is destroyed; upon the other hand the temperature may be lowered to a considerable extent without the cell being killed. An increase of heat above that at which the cell normally exists causes a marked increase in its vital processes until the heat rigor point (40°C.) is reached when a coagulation takes place and the cell is killed. Lowering of the temperature below the normal produces a gradual lessening of activity until cold rigor (0°C.) point is reached when the cell passes into a *narcotic state.* Apparently cells may remain in this state for a considerable length of time without their vitality being destroyed, for if they be gradually warmed up to their normal temperature their vital functions are resumed.

Light, in the higher order of animals, is supposed to be a stimulus to the organs of vision only. In some of the lower animals other tissue cells, especially those of the skin, respond to its stimulation.

Electrical stimuli, when applied in the form of weak currents, cause an increase, strong currents a decrease, in cell activity. If the latter are continued for a considerable time they will cause the death of the cell.

Chemical stimuli are almost numberless and at present their action is not thoroughly understood. Some cause contraction, some increased movements and others increased secretory activity, etc. A striking feature of the unilateral action of chemical stimuli is that known as *chemotaxis*. This is the property possessed by certain cells of responding to the stimulation of chemical substances introduced into, or formed in the body. Some substances cause cells to approach them (*positive chemotaxis*); others repel them (*negative chemotaxis*). The leukocytes respond quickly to this form of stimulation. Such movements may be produced by the addition or subtraction of water, producing relaxation and contraction, respectively. Chemical action is also dependent upon the concentration of the salts and upon the contained electrolytes. Chemotaxis plays a very important part in many physiological phenomena, as for example, the tendency to seek oxygen, the attraction of leukocytes toward bacterial activity and the attraction exerted by the ovum upon the spermium.

Reproduction is the process by means of which a cell or an organism propagates itself and continues its life history. Without this or an analogous process, life would soon cease to exist. It is of two varieties, **direct, amitosis** or **budding** and **indirect, mitosis** or **karyokinesis.** Of these, the latter is the more common.

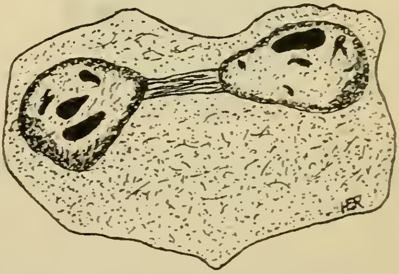

Fig. 27.—Amitosis of a Cell of the Bladder. (*After Nemileff.*)

Amitosis.—This form of cell division was formerly thought to be the usual method, but it is now known to be restricted to some cells of the bladder, cells of Sertoli of the testis, giant cells of the bone-marrow and occasionally to leukocytes and gland cells. By some it is considered a sign of degeneration. The nucleus in this form of cell division divides without the intranuclear network undergoing the same complicated changes as in the indirect method.

The nucleus first becomes constricted; this constriction gradually increases and finally divides the nucleus into two equal parts forming daughter nuclei; these daughter nuclei draw away from each other by ameboid movement. At times the complete division is delayed and the two nuclei are connected, for some time, by a narrow thread of nuclear material. Division of the cytoplasm takes place by the development, at first, of a constriction in that portion of the cell body between the nuclei and then finally by the entire separation of the daughter cells thus formed. Like the nucleus the cytoplasm may, in some instances, remain connected, or its division may be delayed while the nuclei go on dividing, the result being an accumulation of nuclei and the formation of a multinucleated cell.

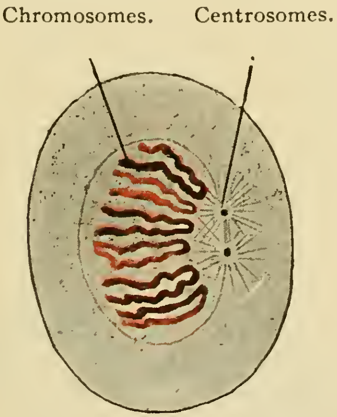

Fig. 28.—Scheme of the Close Skein and the Division of the Centrosomes. (*Stöhr's Histology.*)

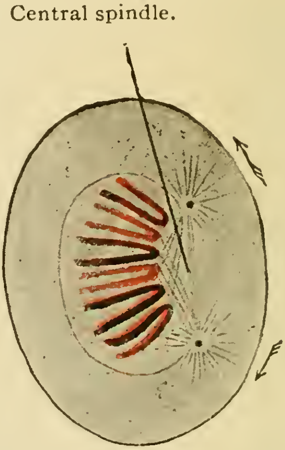

Fig. 29.—Scheme of the Loose Skein and Separation of the Centrosomes. (*Stöhr's Histology.*)

Mitosis is a very complex process, in which the nucleus plays a very important part. The cytoplasm is almost passive until the late stages of the process. The various stages are the **prophase, metaphase, anaphase,** and **telophase.** These are not absolutely separable from one another. The changes that occur may be grouped under three heads—*nuclear*, *centrosomic* and *cytoplasmic.*

Prophase.—The *nuclear* changes are quite complex. Whereas the *chromatin* is ordinarily arranged as an irregular network, when division begins the irregular twigs of the network gradually become smooth, and form, usually, a single thin closely convoluted thread, called the **spirem,** or **skein.** This thread consists of a double row of chromatin granules (chromioles). The thread becomes thicker and shorter, and soon separates into a number of segments called **chromosomes.** This sometimes occurs before the spirem is formed. The chromosomes become **U**- or **V**-shaped, and arrange themselves along the equator of the cell with the closed ends directed toward a common center, called the *polar field*. This arrangement is termed the **equatorial plate,** or **monaster,** and practically ends the chromatin changes during the **prophase.** The chromosomes vary from two to sixty-four in different species.

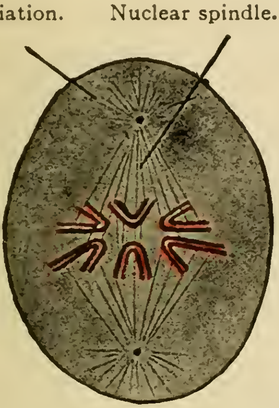

FIG. 30.—SCHEME OF THE MOTHER STAR, OR EQUATORIAL PLATE. (*Stöhr's Histology.*)

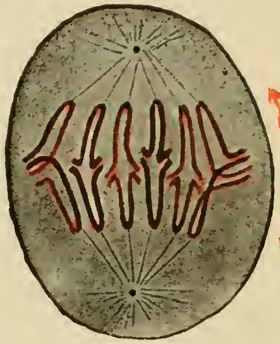

FIG. 31.—SCHEME OF METAKINESIS, SHOWING THE NUCLEAR SPINDLE. (*Stöhr's Histology.*)

The **chromosomes** are always even in number, and the same number is always formed in each cell of the same species. In *man*, the number is said to be twenty-four.

The *nuclear membrane*, during these changes, has gradually become more and more hazy, and finally *disappears*. The *achromatin* is released, and mixes with the cytolymph.

The *nucleolus* likewise gradually fades and disappears to assist in the formation of the central spindle (Ferguson).

The *centrosome* is the *dynamic center* of the cell. It divides into two portions (if within the nucleus, it passes first into the cytoplasm), each of which becomes surrounded by its own *attraction sphere*. These centrosomes gradually move apart, through an arc of 90°, to opposite poles of the cell. During this change, some of the intervening rays remain in contact, forming a spindle of delicate threads, which is complete when the centrosomes reach their polar position. This is the **central,** or **achromatic spindle,** and the threads are of the utmost importance, and become attached to the chromosomes of the equatorial plate.

With the formation of the equatorial plate and central spindle, the **prophase** ends. Variations, too numerous to describe, occur, but the above is the usual course in this stage of mitosis.

Metaphase.—This is the stage during which the chromosomes divide and separate. It concerns the chromatin chiefly and is of short duration.

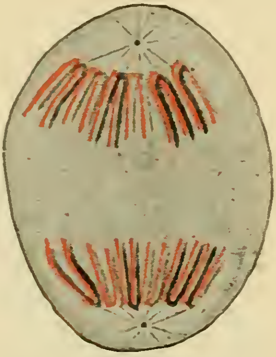

FIG. 32.—SCHEME OF THE DAUGHTER STARS. (*Stöhr's Histology.*)

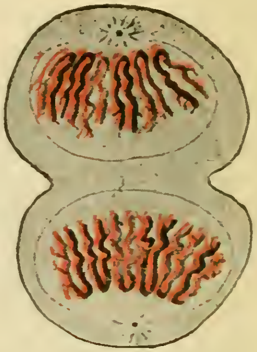

FIG. 33.—SCHEME OF DIVISION OF THE PROTOPLASM FORMING DAUGHTER CELLS. (*Stöhr's Histology.*)

The chromosomes *divide longitudinally* into two equal portions. This cleavage occurs at the closed end first, and as it proceeds, the *daughter chromosomes* become separated, one-half being drawn toward the one centrosome, and the other toward the second. This gives rise to a second spindle, the **nuclear,** or **chromatic spindle.** The separation is affected by the traction exerted upon the daughter chromosomes *by the threads of the central spindle.*

Anaphase.—This is the stage of complete separation of the chromosomes. The latter collect around their respective centrosomes, and remain connected to the opposite set, for some time, by the central spindle threads. The figures thus formed are the **diasters,** or **daughter stars.**

Telophase.—This stage is concerned with the cytoplasmic changes and the formation of a resting nucleus. Up to this time, the cytoplasm has been practically quiescent.

The chromosomes collect around the centrosomes, and unite to form a *close skein.* Lateral twigs are developed that anastomose to form the *nuclear network*, a *nuclear membrane* is formed and a *nucleolus* appears.

The hitherto inert cytoplasm shows changes. A plate of granules (*cell-plate*) appears at the equator of the cell, and separation occurs in the intervening space until two separate masses are formed; these are the **daughter cells.** Frequently the centrosome divides at this stage forming a *diplosome.*

The above changes are usually succeeded by a period of rest.

Although apparently a long process, only about *one-half hour* is consumed in the division of human cells, but the cells of lower animals require a longer period (three hours).

In the case of *giant cells*, the nucleus divides and redivides, while the cytoplasm remains unchanged. They may also be formed by the fusion of the cytoplasm of a number of cells with the retention of the individuality of the nuclei.

As all cells are developed from preëxisting elements, it is but natural that the original cell of the body, the **ovum,** should be of greatest interest. It is the most characteristic cell of the body, and is secreted by the ovary. It is the largest cell, and illustrates the individual parts well.

The **ovum** consists of a limiting wall, the **vitelline membrane,** that may be well developed. Within this is the cytoplasm, **vitellus,** which consists of two parts—the **deutoplasm,** or **nutritive yolk,** and the **animal protoplasm,** or **formative yolk.** This is of importance, *embryologically.* Within the vitellus is found the nucleus, or **germinal vesicle,** which contains a deeply stained nucleolus, or **germinal spot.** The centrosome is to be seen in unripened ova. After maturation this body disappears. In what might be termed an *embryologic ovum*, there are two layers external to the vitelline membrane, the **zona pellucida** and the **corona radiata.** Of these, the former is the more important, because of the part which it plays in the early stages of development.

There are a number of processes that occur in the ovum before it can develop into an offspring. Of these, the most important are **MATURATION** and **FERTILIZATION.** The *former* occurs, usually, in the ovary, or shortly after ovulation, and the *latter*, as a rule, in the oviduct.

Maturation is the process by which part of the chromatin and a small portion of the cytoplasm are extruded in the form of two minute structures called **polar bodies.** It is a *modified karyokinesis*, and its object is unknown. All ova must pass through this process before they can be fertilized.

Fertilization is the process in which the male and female elements unite to form a complete and perfect cell, which, by division, gives rise to the cells that ultimately form the whole body.

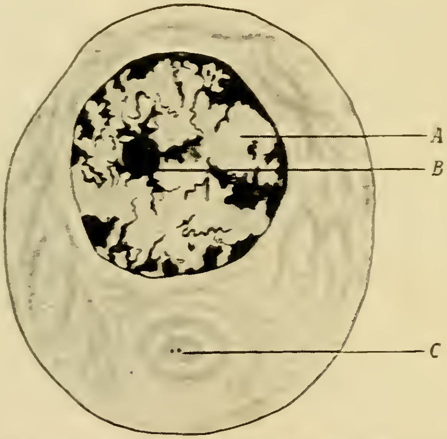

FIG. 34.—UNRIPENED OVUM FROM A YOUNG GUINEA-PIG.
A, Nucleus; *B*, nucleolus; *C*, centrosomes in the attraction sphere.

The **male element,** or **spermatozoön,** or **spermium,** consists of **head, middle-piece** and **tail.** Of these the **head** and **middle-piece** representing the **nucleus** and **centrosome,** *respectively*, of a cell of the testicle, enter the ovum and form *eleven* or *twelve chromosomes.* The chromatin of the germinal vesicle of the ovum also forms *twelve.* By longitudinal cleavage *forty-six* or *forty-eight* are formed of which *twenty-three* or *twenty-four* enter into each diaster and, consequently, each daughter cell. By this process *the descendants of the fertilized ovum contain double the number of chromosomes that existed in either of the original cells before fertilization.* Through the male and female chromatin the offspring receives the characteristics of its parents.

One-half of the spermia contain *eleven* chromosomes and the other half contain *twelve*. The ovum always contains *twelve*. If the ovum is fertilized by a spermium containing *twelve* chromosomes the offspring will be a *female*. If the fertilizing spermium contained only eleven chromosomes the offspring will be a *male*. The male somatic cells are said to contain but twenty-three chromosomes while the somatic cells of the female contain twenty-four chromosomes.

After fertilization the ovum divides and redivides, forming an irregular mass of cells called the **morula, or mulberry mass**. Certain of these cells form a complete layer that surrounds the remainder, which constitutes an irregular mass. The layer is the **outer cell-mass** and the latter the **inner cell-mass.** This structure constitutes the **blastula,** or one-layered vesicle. Of these two structures the *inner* is the more important as it persists and forms the whole body while the *outer* assists in the imbedding of the ovum and the formation of the placenta.

The **inner cell-mass** forms two layers, an *outer*, several cells in thickness, the **ectoderm,** or **epiblast,** and an *inner*, composed of but a single layer, the **entoderm,** or **hypoblast.** This is the **gastrula,** or **diploblast.** The ectoderm and entoderm each set aside a number of cells which by multiplication form a third layer, the **mesoderm,** or **mesoblast,** that lies between the two. This structure receives the name of **blastodermic vesicle,** or **triploblast.**

From these three primitive layers all the organs and tissues of the body are formed as follows:

Ectoderm.

The nerve system (cerebrospinal and sympathetic) the retina, the bulk of the crystalline lens, the muscle of the iris and part of the vitreous humor of the eyeball, the epithelium of the cornea and conjunctiva, the epithelium of the internal ear and of the olfactory organ, the medulla of the adrenal.

The epithelial lining of the penile portion of the male urethra, the labia of the female and the glands leading thereto.

The epithelial lining of the mouth and salivary glands, epithelial lobe of the pituitary body, the enamel of the teeth, the cells of the nasal tract and glands leading thereto, to the pharynx, and the lining of the anus.

The epidermis and appendages of the skin, muscles of the sweat glands.

The syncytium of the placenta.

The notochord (*primarily*).

Entoderm.

The epithelial lining of the bladder, the prostate and glands of Cowper, of the prostatic and membranous portions of the male and entire female urethra, vestibule and glands of Bartholin.

The epithelium of the tongue, thymus and thyroid bodies of the parathyroids, middle ear and Eustachian (auditory) tube.

The epithelium of the alimentary and respiratory tracts from the mouth and posterior nares down and the epithelium of all glands opening into these structures.

The notochord (*secondarily*).

Mesoderm.

The vascular system.

The lymphatic system including the large serous cavities, spleen and thymus body (except the corpuscles of Hassal).

The muscle tissues (except the muscles of the sweat glands and iris).

The connective tissues.

Testicles, vas, seminal vesicles, ejaculatory ducts, ovaries, oviducts, uterus and vagina.

Kidneys, ureters and cortex of adrenals.

CHAPTER III

THE TISSUES

From the preceding table it will be seen that all tissues are developed from the three layers of the triploblast. These tissues are grouped, histologically, under four classes, **epithelial, connective, muscle** and **nerve.**

A **tissue** consists of similarly differentiated cells held together by intercellular substance and performing a definite function. The intercellular substance varies with the different tissues. The cells of a tissue may be so arranged as to form an organ or merely a supporting structure.

A **syncytium** is a tissue in which the cell boundaries have never appeared or have disappeared. It arises through the continued division of the nucleus without the attendant division of the protoplasm, or through the fusion of a great number of cells with an attendant loss of cell boundaries. It represents an extensive mass of nucleated protoplasm.

EPITHELIUM

The epithelial tissues are characterized by the small amount of the intercellular cement. The cellular elements are usually prominent, and rich in granular cytoplasm. They are found lining cavities and covering surfaces that communicate normally with the air and usually secrete, although they may also have an excretory, absorptive, or protective function or receive sense impressions (special sense). Lymph spaces may exist between them and nerve fibers terminate upon them. They are soft and vary considerably in shape in the different organs. As the shape is constant for the various varieties this condition lends itself to the classification of epithelium. In some hollow organs, however, the form of the cells varies considerably at different times depending upon the degree of distension (urinary bladder). Epithelial tissues are avascular and may be derived from any of the layers of the triploblast. The cells vary in size, form and arrangement, as will be seen later. Simple epithelial cells either secrete or assists in secretion while the stratified cells usually have a protective function.

The epithelial cells may be arranged in a single layer of elements and this constitute is called *simple epithelium.* When several layers of cells are present the form is then *stratified epithelium.* In the *latter* case the variety takes its name from the surface cells as will be seen later. In this form the basal cells are always columnar elements and the intermediate cells are polyhedral. The superficial cells of a stratified epithelium are derived, by division, from the lower layers and when these superficial elements are cast off they are replaced by cells from the layer beneath them. In the simple epithelia when a few cells are lost they are readily replaced by the reproduction of the neighboring cells but when a large surface or area is destroyed or lost then the replacement is very difficult or impossible. In the latter instance the condition leads to serious pathologic conditions.

The *intercellular substance,* or *cement* varies in quantity. Between the columnar cells of the stomach and intestine it is usually abundant, especially so near the distal extremities of the cells where it forms what is known as the *terminal bars.* this intercellular cement responds readily to silver nitrate staining method.

For convenience of description, the cells are classified as follows:

1. **Squamous.**
    (*a*) SIMPLE.
    (*b*) STRATIFIED.
    Modified.
3. **Ciliated.**
    (*e*) SIMPLE.
    (*f*) STRATIFIED.
4. **Goblet cells.**
2. **Columnar.**
    (*c*) SIMPLE.
    (*d*) STRATIFIED.
5. **Transitional cells.**
6. **Pigmented.**
    Specialized.
7. **Neuro-epithelial.**
8. **Glandular.**

1. **Squamous.**—(*a*) The **simple squamous** cells consist of a single layer of flattened elements, each containing a large nucleus.

This is usually in the center, and has an oval, or round form. The cytoplasm may constitute so thin a layer that the nucleus produces a bulge. They occur in the descending limb of Henle's loop, the capsule of Bowman in the kidney, the alveoli of the lungs, and in parts of the ventricles of the brain.

(*b*) The **stratified squamous** variety consists of many layers of cells that are unlike in form. The lowest layer, the *germinal stratum*, is columnar, while those cells just above are polygonal. The succeeding cells become more and more flattened, forming the squames, or scales, from which this variety receives its name. These scales may overlap one another and be keratinized, as in the skin. The cells of the deeper layers of all stratified epithelium are all separated from one another by spaces bridged by protoplasmic processes that connect the various cells together. These spaces vary in extent

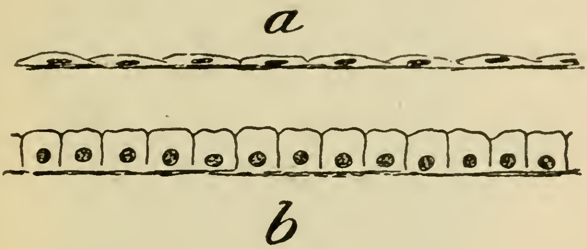

Fig. 35.
(*a*) Simple squamous cells. (*b*) Simple cuboidal cells.

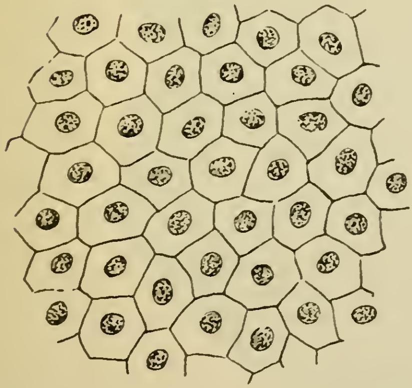

Fig. 36.—Surface View of Squamous Cells of Frog's Skin.

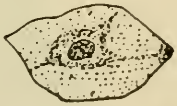

Fig. 37.—Squamous Cell Isolated.

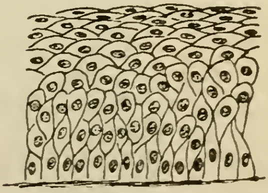

Fig. 38.—Stratified Squamous Epithelium.

at different times. These elements were formerly classified as *prickle cells.*

In stratified epithelium the number of layers varies from five to thirty or more. The stratified squamous variety has the greatest number. The cells of the deeper layers are all soft and show karyokinetic figures, indicating reproduction that gives the cells of the superficial layers. Toward the surface the cells become harder and ultimately keratinized forming then the protective scales of the surface of the layer. The amount of keratinization depends upon

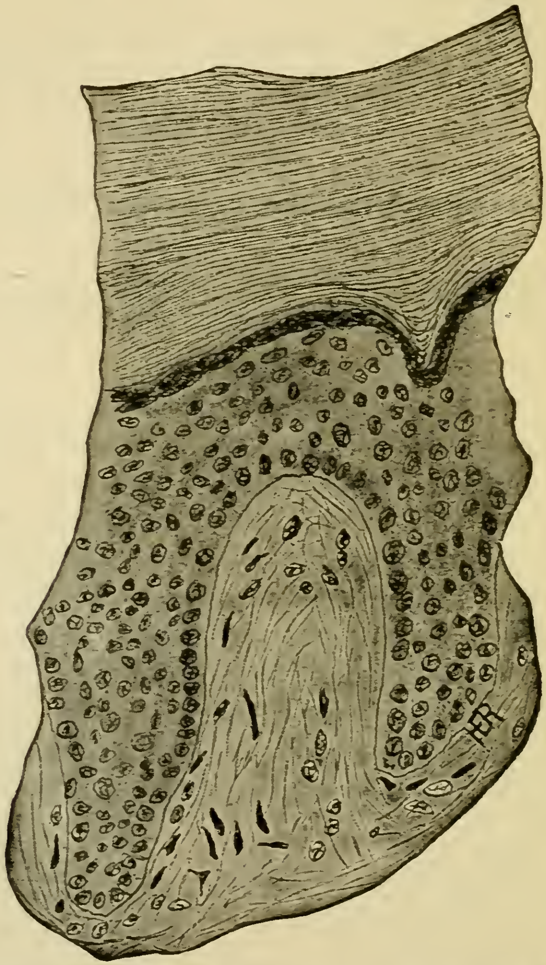

FIG. 39.—SKIN OF THE PALM OF A CHILD AT BIRTH SHOWING STRATIFIED SQUAMOUS EPITHELIUM. (*Radasch, Reference Handbook of the Medical Sciences.*)

the location of the layer; upon the surface of the body where the greatest amount of protection is desired the keratinization is most extensive. Even here it varies according to the use of the part; upon the soles and palms, where the skin is most used, the layer of keratinized scales is thickest; upon the outer parts of the upper and lower extremities and the back (most exposed parts) it is next in quantity; upon the inner parts of the extremities and the ventral thoracic wall it is less marked. The dryness of all of these parts, due to the constant and rapid evaporation of the perspiration, is an important factor in this process of keratinization. In those parts of the body supplied with stratified squamous epithelium, but where there is constant moisture (mouth, esophagus, lips, vagina, etc.), the amount of keratinization is at a minimum in man. In lower animals the keratinization of the epithelium of the tongue and esophagus is more marked than upon the surface of the body.

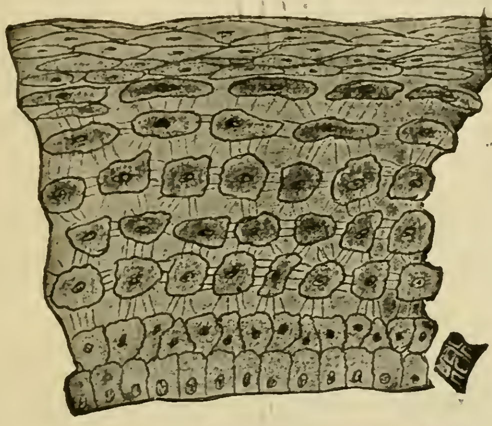

Fig. 40.—Stratified Squamous Cells Showing Prickle Cells. (*Radasch, Reference Handbook of the Medical Sciences.*)

This process of keratinization is a chemical change and is accompanied by changes in the nucleus. The process starts in the cells above the prickle layer. The nucleus becomes less chromatic and somewhat flattened and the cells body likewise becomes elongated. The cytoplasm shows a number of coarse granules of *eleidin* and *keratohyalin* and as the process continues the cells become more scale-like and keratin is formed. By this time the cells in which these changes have been produced are near, or at the surface, to which region they have been pushed by the reproduction of the cells underneath and the desquamation of the cells superficial to them.

Stratified squamous cells are found covering the body as the epidermis, lining the mouth, tongue, pharynx, esophagus, epiglottis, vocal cords and the anus and vagina.

2. **Columnar.**—(*c*) **Simple columnar** cells are tall, cylindric elements arranged in a single layer. The nucleus is usually oval, and found nearer the base than the center of the cell. Protoplasmic bridges are said to exist and the intercellular cement is usually abundant, forming the terminal bars. The cytoplasm may be granular or fibrillar and contain fat or other products. The appearance of the cytoplasm usually depends upon the state of secretory activity of the cell.

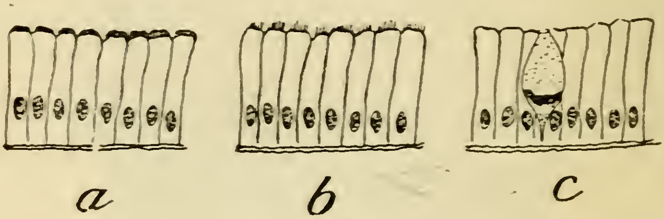

FIG. 41.

a. Simple columnar showing cuticular border. *b*. Simple ciliated cells. *c*. Simple columnar and goblet cells.

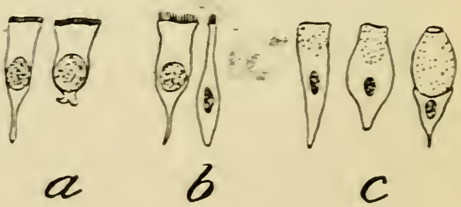

FIG. 42.

a. Isolated columnar cells. *b*. Isolated ciliated cells. *c*. Three stages of goblet cells.

The variety is found in the stomach and intestinal tract, the penile portion of the urethra, glands of Cowper and Bartholin, prostate, gall-bladder and seminal vesicles, and in many gland ducts. In the intestine these cells, upon their exposed surface, have a layer of differentiated cytoplasm forming a partial membrane; this is called a *cuticular border*. Low columnars are often called *cuboidal*.

Pseudostratified cells are simple columnar, or ciliated, cells, in which the nuclei are not all basal, but occupy different levels, thus giving the appearance of several layers of cells, where, in reality, but a single layer exists. These are found as ciliated elements in the oviducts, uterus and middle ear and as nonciliated elements in the seminal vesicles (maybe simple) and prostate, according to some writers.

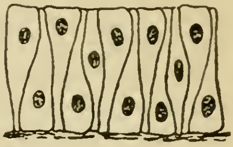

FIG. 43.—PSEUDOSTRATIFIED CELLS.

(*d*) **Stratified columnar** cells consist of a number of layers of columnar elements superimposed upon one another. The cells are not as large as the preceding. They occur in the vas deferens, membranous urethra and the ducts of some glands.

3. **Ciliated Cells.**—(*e*) **Simple ciliated** cells are simple columnar elements, which bear, upon their exposed surface, a varying number of hair-like processes called cilia. These possess a motion that is directed toward the outlet of the organ in which these cells are found. It is said that in lower animals the action of the cilia can be reversed. They line the smaller bronchioles, spinal canal, accessory spaces of the nasal fossæ and the ventricles of the brain.

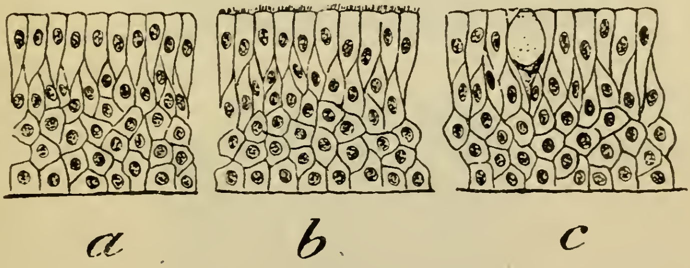

FIG. 44.

a Stratified columnar cells. *b*. Stratified ciliated cells. *c*. Stratified columnar cells showing goblet cells.

Within the cell each cilium is connected with a pair of granules called *basal body;* these latter are centrosomic in origin. As these basal bodies are not present in the cells of the epididymis and spinal canal their cilia are not considered true cilia. The cytoplasm may contain vacuoles, pigment granules and even secretory granules.

(*f*) The **stratified ciliated** cells are practically stratified columnar

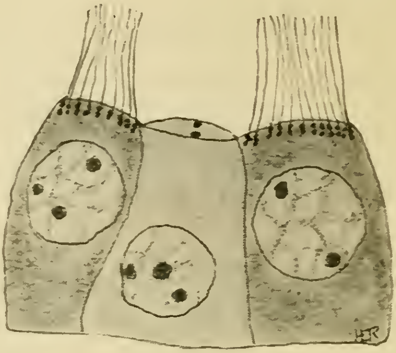

FIG. 45.—CILIATED CELLS SHOWING THE BASAL PARTICLES. The middle cell shows a diplosome. (*After von Lenhossek.*)

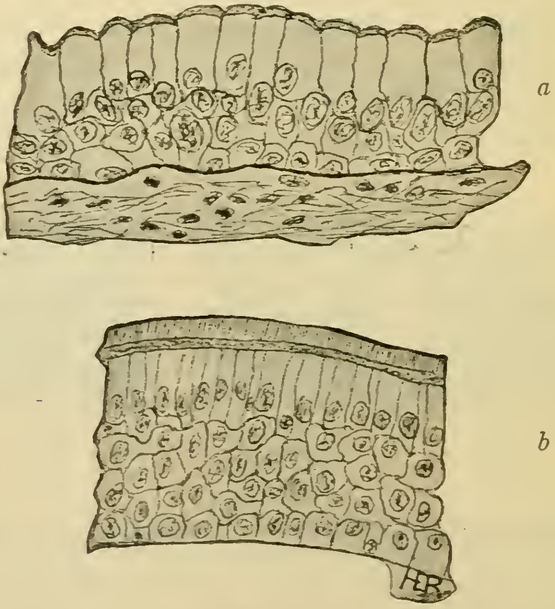

FIG. 46.

a, Stratified columnar cells of the vas deferens of a guinea-pig showing a cuticular border. *b*, Stratified ciliated cells of the trachea of a child at birth showing a cuticular border. (*Radasch, Reference Handbook of the Medical Sciences.*)

cells, of which the exposed layer alone possesses cilia. They are found in the epididymis, first part of the vas, Eustachian tube, upper part of the pharynx, in the larynx, trachea and nasal tract.

4. **Goblet cells** are cells of the cylindric type, distended with a peculiar secretion called *mucin*. They really represent *unicellular glands*. When these cells are filled they resemble goblets, hence the name. The secretion makes its appearance in the form of granules (*mucinogen*) which increase in number and size and respond to special stains (*muchematein*). When secretion occurs the granules absorb water, swell and coalesce to form a single droplet. When the secretion has been discharged the cells are long and slender, the part containing the nucleus projecting on either side. These cells are met with in the gastro-intestinal and respiratory tracts.

5. **Transitional cells** represent a peculiar intermediate form of protective epithelium between the stratified squamous and stratified columnar varieties. The genetic layer consists of columnar cells and these are succeeded by several layers of polygonal or pyriform elements. The surface cells vary as follows: in the bladder and ureter, when empty, these cells are polygonal or cuboidal, while in the distended bladder they are flattened. In the urethra they remain polyhedral. This variability of shape indicates the *elasticity* and *extensibility* of epithelium, as pointed out by Harvey.

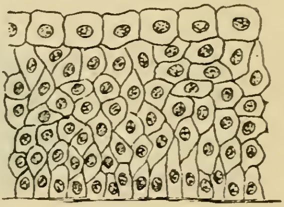

FIG. 47.—TRANSITIONAL CELLS.

Keratinization of this variety seldom occurs and the shape of the cells is so characteristic that they can readily be distinguished from vaginal, urethral and epidermal cells in the urine.

This variety is found in the pelvis of the ureter, the ureter, bladder, first portion of the male urethra and the greater portion of the female urethra.

6. **Pigmented cells** are polygonal, or columnar elements in which the cytoplasm contains a number of pigment granules. This pigment may be diffuse or granular in character and is probably intracellular in origin. The polygonal cells are found in the epidermis of colored races and around the nipples and genitals of Caucasians. In the retina of the eyeball the cells are irregular in form and the position of the pigment depends upon whether the retina has been fixed with the exclusion of light or not. The pigment granules may be so numerous as to obscure the various parts of the cell.

7. **Neuro-epithelial cells** are epithelial cells that have become so differentiated as to perform a special sense function. They differ according to location, and will be described under each special sense. They occur in the retina (*rods and cones*), in the internal ear (*hair cells*), in the olfactory mucous membrane, (*olfactory cells*) in the taste-buds (*gustatory cells*) and as tactile cells.

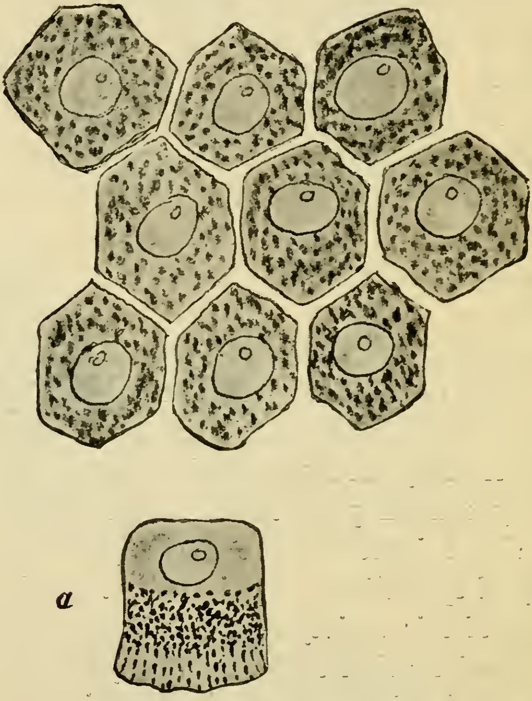

FIG. 48.—PIGMENTED CELLS OF THE HUMAN RETINA (SURFACE VIEW). *a*. Cell showing pigmented processes. (*After Greef from the Reference Handbook of the Medical Sciences.*)

8. **Glandular cells** are concerned with secretion or excretion and vary according to the nature of the gland in which they are found, as in the liver, pancreas, etc. The cytoplasm is usually granular indicating the formation of a secretion. Immediately after secretion the cytoplasm is usually clear.

MUCOUS MEMBRANES

Mucous Membranes.—Within the body proper are a number of recesses and tracts that communicate normally with the exterior;

these are lined with epithelial cells that are supported in an especial manner, constituting, thus, *mucous membranes*. These in themselves are quite extensive, but their area is greatly increased by offshoots in the form of glands, ducts, recesses, folds and projections (villi). These tracts are the alimentary, respiratory, urinogenital systems and lacrimal apparatus and their connected glands and cavities.

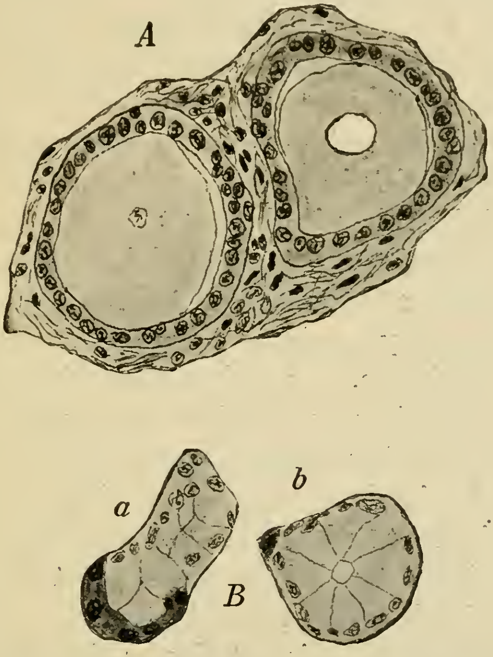

FIG. 49.—GLANDULAR EPITHELIAL CELLS.

A, Tubules of the human thyreoid gland showing cuboidal cells. *B*, Tubules of a human submaxillary gland; *a*, tubule showing a demilune; *b*, cross-section of a tubule. (*Radasch, Reference Handbook of the Medical Science.*)

To any and all of these the air has access. They all have their beginnings or endings, or both, at the skin and the line of connection is usually sharply marked. The lining of each tract may differ somewhat from that of another, as their functions are not the same but the general structure is the same in all cases.

These membranes are firmly attached to the underlying structures in certain regions, as in the nasal cavities and their accessory fossæ; in other regions, as the stomach, bladder, etc., the connection is rather loose permitting of considerable distention of these organs without injury to the lining membrane. In some organs the mucous membrane is nearly even and regular in course, as gland ducts; in others it is formed into finger-like projections (*villi*), as in the small intestine. In still other organs it is thrown into extensive folds, as the intestines, stomach and bladder. By the formation of villi and folds the absorptive and secretory surfaces are enormously increased without a marked increase of the bulk of the organ.

Normally mucous membranes are soft, opaque, or nearly so, slimy and easily torn by moderate force. Ordinarily they are pinkish in color but the depth of color depends on the organ and its function. The color is due to the vascularity of the part and naturally where the vascularity is greater, the color will be deeper, as for instance, in the stomach, pharynx and rectum. The color is deeper in the fetus and infant than in the adult.

A **typic mucous membrane** consists of *four layers*, (1) *epithelium*, (2) *basement membrane* (3) *tunica propria*, (4) *muscularis mucosæ*.

1. The *epithelium* may be of any variety and will depend upon the function of the membrane. In such regions where protection alone is desired the epithelium is stratified squamous, transitional, or stratified columnar. Where secretion and excretion are being carried on, the variety is simple columnar, cuboidal or goblet. Where protection is desired and where, at the same time, the removal of small foreign bodies, entangled in mucus, must be maintained, the variety is either simple or stratified ciliated.

2. The *basement membrane* is not always demonstrable and when noticeable it is thin and apparently homogeneous. It usually consists of flattened cells that form a continuous layer or may be united to one another by protoplasmic processes, making thus, a sort of network. Some state that it is secreted by the epithelial cells but in all probability it is derived from the tunica propria.

3. The *tunica propria* consists of a delicate network of fibroelastic tissue that varies in different organs. In some organs (esophagus) the white fibrous tissue predominates and is more closely packed and therefore tougher. In other organs, as stomach and intestines, it is looser as glands and lymphoid tissue in great abundance are found here. It is this layer that supports the capillary blood-vessels, smaller lymph channels and the smaller nerve trunks and fibers. Here are also found, in certain organs, glands and lymphoid tissue.

In the small intestine the tunica propria is thrown into an enormous number of finger-like projections called *villi*. These structures are of the greatest importance in the absorption of the digested food products.

4. The *muscularis mucosæ* is not present in all mucous membranes. It consists of involuntary nonstriated muscle tissue arranged in two layers. The fibers of the inner layer run transversely while those of the outer layer run longitudinally.

The functions may be classed as *absorption*, *secretion*, *excretion* and *protection*.

1. *Absorption.*—As a result of the action of digestive fluids the food ingested is converted into substances that are absorbable. This process is carried on chiefly by the villi of the small intestine. By a "selective action" of the simple columnar epithelial cells covering the villi the water and inorganic salts are passed through and ultimately reach the blood-vessels. All of the sugars, except possibly lactose, are converted into levulose or dextrose and as such are taken into the epithelial cells and transferred to the blood-vessels. In whatever form the carbohydrates are absorbed they never leave these cells except in the form of levulose or dextrose. Proteins are converted into peptones by the digestive fluids and as such are absorbed by the epithelial cells of the villi. Native proteins are also absorbed by the mucosa of the large intestine. After absorption the epithelial cells convert these peptones into plasma-albumen and as such are given over to the blood-vessels. Recent investigation seems to point to the fact that the end products of protein digestion are not peptones but less complex bodies, as *polypeptids*, *peptids* and *amido-acids*. It is these simpler products that these epithelial cells convert into plasma-albumen and plasma-globulin. Fats are believed, by some investigators, to be converted into an emulsion during digestion and from this emulsion the fat globules are taken by the epithelial cells and passed through them to the lymph vessels. Others believe that as a result of digestion, fats are converted into soaps and glycerin. The epithelial cells take these and reconstruct fats within the cell-body and the fat is then passed to the lymph vessels where with the lymph it constitutes *chyle*.

2. *Secretion.*—This term is applied to the fluid that is made by

the vital activities of the epithelial cells from the constituents of the lymph that surrounds them. This juice is used in the vital processes of the body. Such juices are the pancreatic and gastric, saliva, bile, etc., and the various internal secretions. These fluids are formed as the results of chemical changes within the cells. That the epithelial cells of the stomach give rise to an entirely different juice than those of the liver or other glands is probably due to the difference in histologic and chemical structure. These epithelial elements are not always active but discharge their secretions at periodic intervals and in between enjoy a period of rest and recuperation. During the inactive period certain substances, as mucin, glycerin, proteins and antecedents of enzymes, accumulate in the cells, as the result of cellular activity; these substances constitute the secretion. At such times the blood supply is not great. During glandular activity the organ becomes red, due to increased vascularity, and as a result a rapid transudation of water and salts into the lymph spaces occurs. As the water passes through the cells the above-mentioned constituents are dissolved and are ultimately discharged into the lumen of the ducts.

The formation and discharge of the secretions are controlled by the nerve system. These nerve centers may be excited by emotional states or by impressions upon the terminals, as for instance, the flow of saliva is increased either by the presence of desirable food in the mouth, or by the mere thought or odor of desirable food.

3. *Excretions.*—The formation and elimination of waste products which, if retained, would lead to injurious results, constitute excretion. These waste products are emptied into the blood and are the results of the activities of the cells and tissues. Epithelial cells are the prime factors in excretion and are assisted by osmosis and filtration. The chief excretions are the urine, perspiration and bile. The urea and salts of the urine are not made by the kidneys but are merely eliminated by these organs. The epithelial cells of the kidney have a selective power by means of which they take these substances from the blood and simply pass them into the uriniferous tubules. The liver does not make the cholesterin (the excrementitious part of the bile) but merely removes it from the blood and passes it to the intestine. The sweat glands merely remove a small amount

of urea and certain inorganic salts, by selective action, and these with water from the blood constitute perspiration.

4. *Protection.*—In certain organs that do not secrete nor excrete, a protective lining alone is required, as in the mouth, esophagus, bladder, ducts of glands, etc. The epithelial cells here are usually of the stratified squamous, stratified columnar or transitional varieties.

SEROUS MEMBRANES

Some writers classify **endothelial cells** as epithelial, but as they are not they will be considered here so as to emphasize the differences between them. When an area of epithelial cells is denuded thereof this area is covered, or healed, by the extension of the epithelial cells at the edges. If this denuded area is not too large the entire part is soon covered by these extended cells. If the area is large then small islands of epithelium taken from other parts of the body and placed upon the denuded area will usually grow and spread, thus covering the uncovered area. On the other hand when the endothelial cells of a serous membrane have been denuded they are replaced by cells from the underlying subendothelial tissue and hence are of connective tissue origin. The structure and functions of serous and mucous membranes differ; lastly the course of inflammations of these two membranes is so different that the lining cells must essentially be different. Although serous membranes are here described it must be remembered that it is for the sake of comparison and not because endothelial cells are considered epithelial cells.

Endothelial, or better **mesothelial, cells** are thin, flattened elements possessing a projecting nucleus. This is because the layer of cytoplasm is so thin that the diameter of the nucleus exceeds it. They are very irregular in outline, having serrated edges, plate-like in the serous cavities and lanceolate in the blood-vessels. They are held together by a small amount of intercellular cement and protoplasmic processes. The cytoplasm is usually clear and apparently structureless and may even show the fibers passing from cell to cell. The free surface of the endothelial cell is said to be covered by a thin layer of vertically striated cytoplasm. At intervals the cells do not approximate absolutely forming thus, the *stigmata.* These are supposed to be openings leading into lymph spaces and vessels of the serous cavities. They are considered by some as mere artifacts. In the abdominal peritoneum of the frog normal openings, the *stomata,* exist; these are bounded by specialized *guard cells.* The endothelium of the capillaries is said to be contractile. Endothelial cells never occur in more than a single layer and are plate-like though those of joint-cavities may have a cuboidal form. In this they resemble the fetal mesothelial cells which are of the cuboidal type.

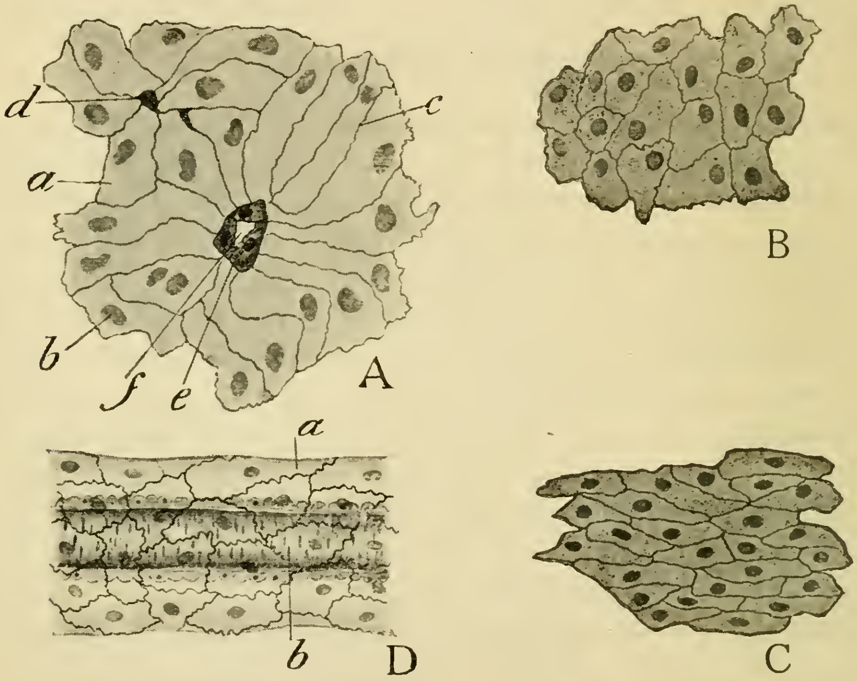

Fig. 50.

A.—Abdominal Endothelium. *a,* Endothelial cell; *b,* nucleus of cell; *c,* cell boundary; *d,* stigmata; *e,* endothelial cells of stomata; *f,* stomata. B.—Mesenteric Endothelium. C.—Arterial Endothelium. D.—Perivascular Lymphatics. *a,* Endothelial cells of lymphatics; *b,* blood-vessel (arteriole).

A **serous membrane** consists of two parts: (1) a *single layer of endothelial cells,* (2) a *layer of subendothelial tissue.*

1. The *endothelial cells* are as above described. These rest directly upon the fibroelastic subendothelial connective tissue.

2. The *subendothelial tissue* consists of a thin layer of areolar tissue that consists of a delicate network of white fibrous and yellow elastic tissues. This supports the blood-vessels and the nerves. Lymph spaces are very numerous and if stomata really exist they connect the cavity lined with these lymph spaces.

Serous membranes are quite sensitive being well supplied with afferent nerves. In the peritoneum these terminate in bulb-like expansions; around joint cavities Pacinian bodies are also numerous.

Serous membranes are found lining joint-cavities, bursæ, tendon sheaths, the circulatory and lymphatic systems and the larger serous cavities, the pleural, peritoneal and pericardial.

Characteristics	Mucous membranes	Serous membranes
Where found............	Lining cavities that communicate normally with the air.	In cavities that do not normally communicate with the air (female peritoneal cavity excepted).
Lined by...............	Epithelial cells of any variety.	Endothelial (Mesothelial) cells, one layer.
Secrete..................	With few exceptions.	Do not.
Structure...............	Epithelial cells, basement membrane, tunica propria, muscularis mucosæ.	Endothelial cells, subendothelial connective tissue.
Represents.............	All four varieties of tissue.	But two varieties (neither muscle nor epithelial tissues).

Minot considers the cells that line the pleural, pericardial and peritoneal cavities as *mesothelial*, while those of the circulatory and lymphatic systems he calls *endothelial.*

GLANDS

A description of epithelial tissues would not be complete without a consideration of **glands.** The term gland is loosely applied to some organs that, strictly speaking, are not true glands in the sense of epithelial structure. Most of the glands are offshoots or derivatives of mucous membranes and the great majority still retain their connection in the completed condition. Glands may be **unicellular,** as the **goblet-cell,** or **multicellular,** as those that will be considered below. A **gland** is an evagination of a mucous surface, consists of epithelial cells, arranged in definite groups, and performs a physiologic function. These groups are the *secretory units* of the organ.

Glands may be classified in several ways: (1) as to **structure** (2) as to **secretion** and (3) as to **outlet.**

1. **Structure.**—As the secretory units are of different shapes we have the following divisions and subdivisions:

Tubular Glands.
- SIMPLE.
- BRANCHED.
- COILED.
- COMPOUND.

Tubulo-alveolar Glands.

Alveolar, or **Racemose Glands.**
- SIMPLE.
- COMPOUND.

Tubular.—**Simple tubular** glands are mere cylindric depressions in the mucous membrane. They are lined, usually, by simple columnar cells. These rest upon a delicate basement membrane and this is supported by the tunica propria of the mucous membrane. In the stomach the cells are acid, peptic and some goblet cells; in the small intestine the goblet cells predominate near the outlet while the remainder of the gland is lined with simple columnar elements. At the *fundus* of the glands there are certain cells with granular protoplasm; in some of these cells the granules are acidophilic and in others basophilic. Each gland consists of a *fundus, neck* and *mouth.*

Simple tubular glands are found in the cardiac end of the stomach and in the small and large intestines.

The **branched tubular** are like the above, except that the blind end consists of two or more secretory units. Each secretory unit consists of a fundus and neck and the single outlet for all represents the mouth. The lining cells may be columnar, or ciliated, as in the uterus. These glands are found in the fundus and pyloric portion of the stomach, in the duodenum (Brunner's glands) in, the uterus, and in the prostate.

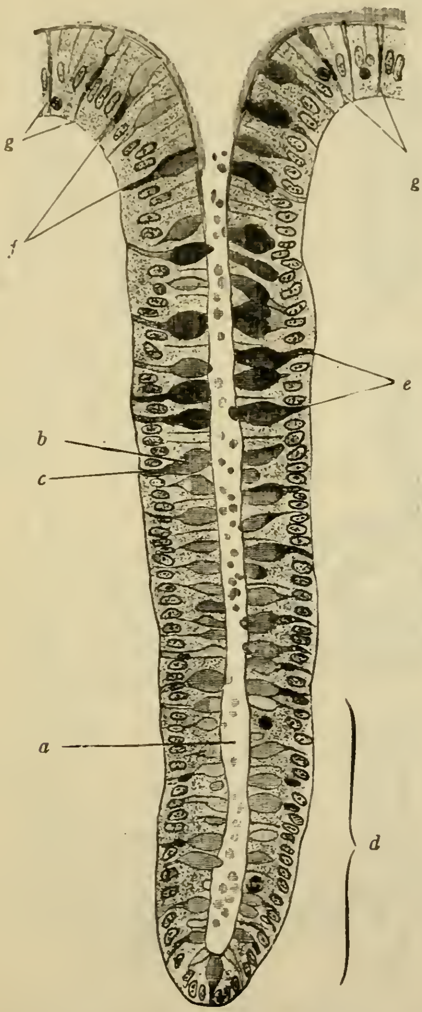

FIG. 51.—GLAND OF LIEBERKUEHN FROM A SECTION OF THE LARGE INTESTINE.

a, Lumen; *b*, secretion of cells; *c*, nucleus and cytoplasm of cell; *d*, fundus cells at the beginning of secretion; *e*, *f*, goblet cells in later stage; *g*, dying goblet cells. (*Stöhr's Histology*.)

Coiled tubular glands are really simple tubes, the secretory portion of which has become coiled and convoluted to occupy as small a space as possible. The lining cells are columnar or cuboidal (low columnar). These rest upon a basement membrane which is further supported by areolar tissue for the capillaries and nerves. Around the outside is a *capsule* that delimits the organ from the surrounding tissues.

Examples of this variety are the sweat and ceruminous glands.

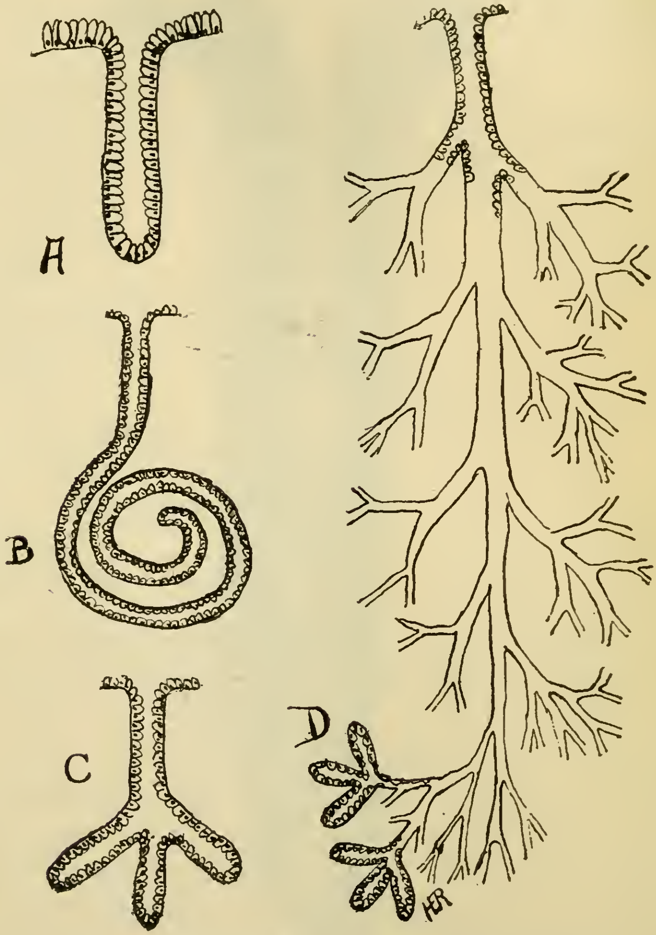

FIG. 52.—DIAGRAMS OF TUBULAR GLANDS.
A, Simple tubular. *B*, coiled tubular. *C*, branched tubular. *D*, compound tubular.
(*Radasch, Reference Handbook of the Medical Sciences.*)

Compound tubular glands are those in which the primitive tubules have divided and redivided until an enormous number of divisions has resulted. Pure examples of this variety are the liver (also called reticular), testicle, kidney, thyreoid, lacrimal and serous glands of the mucous membranes.

A **compound gland** is surrounded by a *capsule* of white fibrous connective tissue that sends in septa that divide the gland into *lobes*. These are further subdivided by smaller septa into *lobules*, the *structural units* of the gland. Within the lobule is a delicate reticulum that forms the supportive tissue of the blood-vessels, nerves, lymph channels and epithelium. This constitutes the *interstitial tissue*. The epithelium, or functionating part, constitutes the *parenchyma*. In the lobule a single layer of epithelial cells rests upon a basement membrane; these cells are arranged in the form of tubules or saccules and represent the *secretory units* of the gland. The cavity or *lumen* in the center of each tubule leads into an *intralobular duct* that connects directly with the units. These ducts are lined with low epithelial cells that rest upon a basement membrane supported by areolar tissue. These ducts unite to form larger ducts; the latter and the larger vessels lie in the interlobular tissue. The interlobular ducts unite to form larger ducts that ultimately form the single *excretory duct* of the gland.

The arteries usually enter at one region, the hilus of the organ. They then divide into branches that follow the larger septa and into branches that lie in the interlobular connective tissue. From these interlobular vessels branches ramify the lobules and form a plexus around the tubules and acini. The venous channels arise from this plexus and have a course corresponding to that of the arterial vessels and form usually one vein that leaves at the hilus. As the tissue spaces around the tubules and acini are very numerous the plasma of the blood transudes into these and bathes the cells with nutrient material and into this lymph the effete materials are also passed from the cells. In the case of glands with sinusoidal capillaries (liver, adrenal, etc.) there are very few tissue spaces and the capillaries penetrate between the epithelial cells and lie in direct contact with them. Vessels also supply the ducts and framework of the organ.

The lymph gradually passes into definite vessels (capillaries) and then into larger channels and is then collected into one or several vessels which leave at the hilus and capsular region (deep and superficial lymphatics).

The nerves of glands are for the vessels and for the epithelial cells. Those for the vessels are vasodilators and vasoconstrictors. By the action of the former the blood supply is increased and therefore the secretion also; the latter have the reverse action. In some instances the vasodilators are derived from the sympathetic nerves and in others from the cerebrospinal nerves through the sympathetic plexuses. The vasoconstrictors usually arise from the sympathetic nerves. The nerves to the epithelial cells are of two varieties, trophic and secretor. The trophic nerves seem to accompany the vasoconstrictors and by their action cause an increase in the secretion products within the cells. The secretor fibers seem to accompany the vasodilators and produce a rapid discharge of the secretion.

A compound tubular gland may be compared to a bunch of tokay grapes, the grapes representing the secretory units and the various stems the ducts. A full bunch of these grapes will show the small groups of grapes forming larger groups and these can readily be likened unto the lobules and lobes of a gland; the various stems represent, excellently, the various ducts, intralobular, interlobular, interlobar and main ducts. The spaces between the various groups and individual grapes constitute the region of the interstitial connective tissue supporting blood-vessels, nerves and lymph channels.

Tubulo-alveolar glands are those in which the terminal tubules possess sac-like evaginations along the walls. Such are the submaxillary, sublingual, mammary glands and the lungs.

The general structure of these glands is like the preceding. A tubulo-alveolar gland may be likened unto a bunch of mixed grapes, some of the tokay variety and some of the ordinary round, or concord variety. Both varieties may be found in the same lobules, or whole lobules, or lobes may consist of just one form.

Alveolar.—The **simple alveolar,** or **saccular,** glands are sac-like depressions extending from the free surface. They are comparatively few in number, and occur as the smallest sebaceous glands.

Each consists of a sac-like structure connected to the epithelial surface by a slender *neck*, or *duct*. The *sac* instead of being lined with a single layer of epithelial cells, as in all of the preceding forms, is filled with a solid mass of very large polyhedral cells. Those cells nearest the duct show signs of degeneration and fatty changes; ultimately they disintegrate entirely and the thick, fatty substance constitutes the secretion (*sebum*). These cells in forming the secretion die. In other glands the secreting cells form secretion over and over and live for a considerable time. In sebaceous glands the disintegrated cells are rapidly replaced by mitosis of the cells toward the basement membrane. Outside of the basement membrane is a tunica propria for the support of blood-vessels, nerves and lymph channels. The peripheral portion of this is condensed to form a *capsule*.

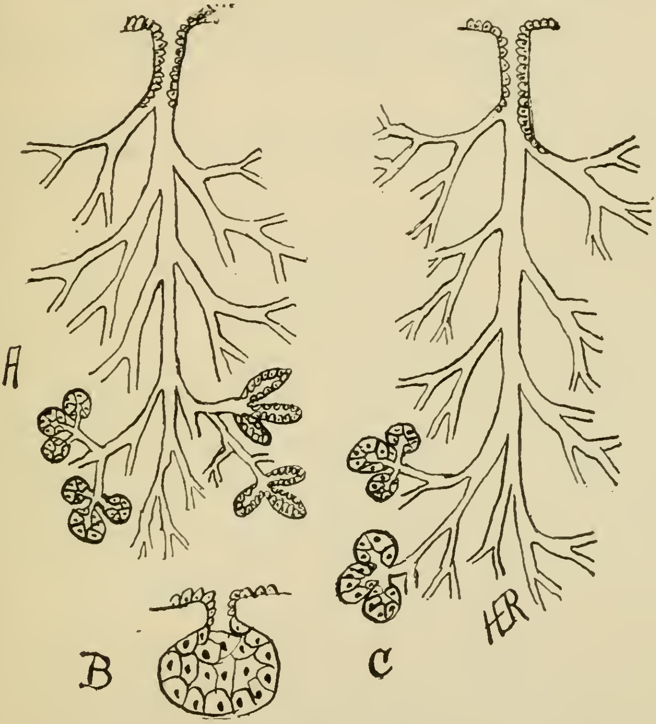

FIG. 53.—DIAGRAMS OF ALVEOLAR GLANDS.
A, Tubulo-alveolar; *B*, simple alveolar; *C*, compound alveolar. (*Radasch, Reference Handbook of the Medical Sciences.*)

The **compound racemose** glands are like the compound tubular, except that the terminal portions are saccular, instead of tubular. Such glands are the pancreas, parotid, and the large sebaceous glands.

The secreting units of the large sebaceous glands, like in the simple form, are filled with a solid mass of epithelium and the changes here are the same as in the simple glands.

2. **Secretion.**—The function of a gland is to give rise to a substance to be used by the body in some of its many processes or to remove waste products (excretions). The former substance is called a *secretion*, and it may be *liquid* or *cellular* (ovum). The liquid secretions may be *serous*, *mucous*, or *mixed*. These terms, applied to the respective glands as well, have reference to the salivary glands alone.

Serous glands are those which form a thin albuminous secretion. The glandular cells respond well to stains. The parotid and pancreas belong to this class.

The appearance of these glands differs when they are in a state of *activity* or of *rest*. At the beginning of the *stage of rest* the cells are comparatively small and shrunken and the lumen of each acinus is large. The nucleus is centrally placed and the cytoplasm is devoid of secretion granules. As the secretion is formed the cytoplasm changes in appearance to either clear or granular according to the gland. In the sweat glands the cytoplasm is clear as the secretion is essentially watery, while in the pancreas and parotid glands the cytoplasm is granular. In the latter glands the secretion is *zygomotic* in character, hence the difference. As the secretion increases the nucleus is forced toward the basal extremity of the cell and the secretion lies toward the lumen end, so that ultimately the cell has a swollen appearance and the lumen is occluded or nearly so.

During the stage of *secretory activity* the secretion is passed into the lumen of the acinus and the cell is smaller and shrunken. The cytoplasm is finely granular, if the secretion has been watery and if the secretion has been granular the cytoplasm is clear.

In many serous gland cells *secretory caniliculi* have been demonstrated. These may open into the lumen of the tubules or into the lymph spaces or blood-vessels. Some of these channels are in the nature of nutrient canals, however. Serous glands stain darkly with the ordinary stains.

Mucous glands are those that give rise to a thick viscid substance.

The cells here stain but lightly with the ordinary stains. Such are the small glands found in the mouth, esophagus, trachea and the sublingual gland, according to some writers.

The cytoplasm of the cells of the mucin secreting glands is finely granular, the nucleus centrally located, the cells smaller and the lumen comparatively large, during the stage of rest. The granules lie in the lumen end of the cells, increase rapidly in size and, after prolonged rest, occupy over half of the thickness of the cells. The granules are much larger than those of the serous glands and respond to the special stains for mucin. As these granules increase in number and size the cells become swollen and the nuclei and cytoplasm are forced toward the basement membrane and the lumen is practically occluded. In the stage of secretion, by the contraction of the cells or by the transudation of water through them (from the blood or lymph), the granules become swollen, dissolve and form a homogeneous mass which is passed from the cell. The cell then is somewhat shrunken and the area formerly occupied by the secretion shows a delicate reticulum in which the new globules of secretion form. The presecretion globules are called *mucinogen* and the finished product *mucin* and they usually behave differently to stains. The secretion granules of the various glands are probably mitochondrial in origin. In most glands the extrusion of the secretion is caused by the action of the nerve system or by *hormones* in the blood.

The cells of mucin-secreting glands stain lightly in contrast to the cells of the serous glands. This is due to the fact that the granules in the serous cells are not readily soluble in the aqueous or alcoholic fixing agents so that they remain and are stained. On the other hand the secretion globules or granules of the mucin cells are readily swollen or dissolved by water or even alcohol so that in fixed cells they were for a long time unobserved. This action is produced even by normal salt solution and serum. They may readily be seen in fresh tissue examined in a 2 to 5 per cent. sodium chlorid solution. If the tissue be fixed in osmic acid vapor, or in a mixture of equal parts of osmic acid (5 per cent. in 3 per cent. sodium chlorid) and saturated solution of potassium bichromate, the granules are undissolved and readily found.

Mucin responds to special stains, *muchematein* and *mucicarmin*. In the fresh state it is clear, slimy and of a pearly white color. Alcohol coagulates it forming a heavy, white, stringy precipitate. It does not respond well to the ordinary stains so the part of the cells containing it looks unstained in the ordinary technic.

In most mucous glands groups of darkly staining cells are seen in the bases of tubules. These cells contain a finely granular cytoplasm and are arranged in cresentic groups called the *crescents of Gianuzzi*, or the *demilunes of Heidenhain*. These cells and groups vary in size in the different glands. Some consider them the resting stages of the mucin-secreting elements and others consider them as entirely different and independent structures. It seems that they are a form of serous cell. The cytoplasm always responds well to the plasmatic stains and also contains secretory canaliculi that empty the secretion into a canalicular system between the cells of a group. From this system the secretion is ultimately passed into the lumen of the tubule. From this it would appear that the so-called pure mucous glands are really mixed glands in that they contain the demilunes.

Mixed glands are those in which both varieties of secretion are formed. The secretory areas are stained darkly or lightly, according to whether they are serous or mucous. The sublingual and submaxillary glands are examples, and of these, the latter is the more characteristic.

The minute structure of these glands will be considered under the **Alimentary Tract.**

The *excretory* glands are the kidneys, lungs and sweat glands. Each will be considered in detail, under its respective system.

3. **Outlet.**—As a rule, all glands, at some period in their development, are connected with the mucous surface by a tube called a duct. This connection, in most instances, persists, but where it disappears, or where it never occurred, the gland becomes isolated, and the term *ductless gland* is applied. Such are the adrenals, hypophysis and thyreoid bodies, parathyreoid, carotid and coccygeal glands, certain areas of the ovary and testis and the areas of Langerhans of the pancreas. The cells are arranged in the form of solid cords, tubules and even alveoli. The delicate reticulum supporting these cells

usually contains capillaries of the sinusoidal type, that is, the epithelium and the endothelium are in contact with each other and lymph spaces are not numerous or are absent. In some instances the lymphatics have a similar arrangement so that the internal secretion is passed directly to the blood or lymph vessels. In the liver the secretory capillaries of the cells are said to communicate with the sinusoid thereby emptying the urea formed here directly into the vascular system.

The glands with ducts pour their secretions, or excretions, into the various tracts with which they are connected.

CHAPTER IV

CONNECTIVE TISSUES

The **connective tissues** are the supportive tissues of the body. They are characterized by the predominance of the *intercellular substance* over the *cellular elements*. The intercellular substance varies in consistency from the liquor sanguinis of the blood and the soft fibrous material of areolar and elastic tissues to the harder cartilage, bone and dentin. This variation is due to the function performed. Although there are many varieties they are all derived from the same embryonic type, mesenchyme, and change as they progress in their development. Even in their adult forms some show their close relationship to one another and while some may be looked upon as different stages of the young type others are distinct modifications, as cartilage, bone and dentin. The cellular elements resemble one another somewhat in the different varieties, are comparatively few in number and are arranged singly or in small groups in the intercellular substance. This matrix or ground substance predominates and it is the variation of this that gives us the different varieties of connective tissue. They often replace one another. The ground substance and the fibers are stained by the silver nitrate method showing the numerous lymph spaces existing in most varieties. The vascularity also varies, some forms having few vessels while others are quite vascular. The connective tissues form the framework and supportive substance of the various organs and the body in general and fill up what ordinarily would be spaces.

In the formation of these tissues the fibroblasts of the mesenchyme reproduce rapidly and secrete a semi-solid intercellular substance. With the fusion of the fibroblasts a syncytial structure is formed. The cytoplasm around the nuclei soon differentiates into endoplasm and exoplasm and in the latter the mitochondria are said to form the fibrils at the expense of the endoplasm. The remainder of these little masses of again isolated cytoplasm constitute the connective-tissue cells. The fibers are of *three types, white, elastic* and *reticular*. Additional fibers are said to be formed by the splitting of these.

For the convenience of description, the connective tissues have been subdivided into the following varieties:

Fibrous.

1. Areolar.
2. White fibrous.
3. Yellow elastic.
4. Mucous.
5. Retiform.

Modified.

6. Adipose.
7. Lymphoid.
8. Cartilage.
9. Bone.
10. Dentin.

11. Blood.

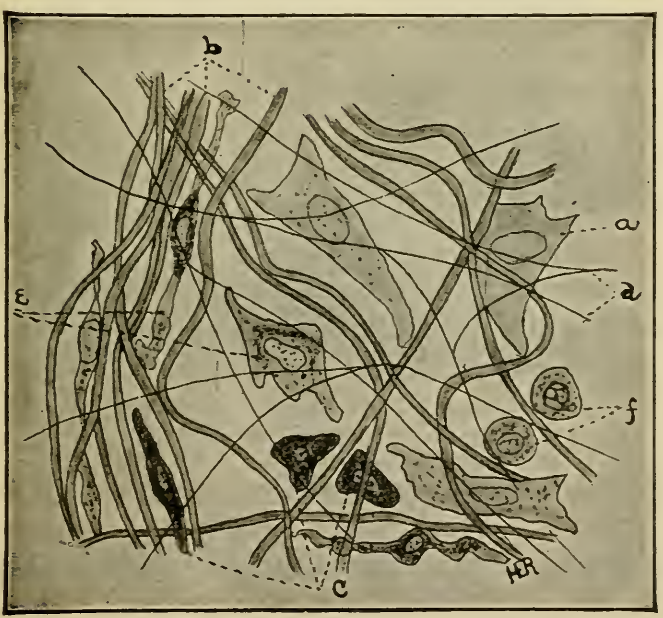

Fig. 54.—Areolar Tissue.

a, Lamellar cell; *b*, bundles of white fibers; *c*, plasma cells; *d*, elastic fibers; *e*, clasmocytes; *f*, granule cells. (*Radasch, Reference Handbook of the Medical Sciences.*)

1. **Areolar tissue** is a delicate, web-like form representing the most widely distributed variety. It consists of an interlacement of white and yellow elastic fibers containing various cellular elements. The spaces thus formed permit of a wide diffusion of lymph over a great

distance. This variety is found binding the skin to the fascia beneath, as the intermuscular septa, surrounding blood-vessels, nerves and lymph channels and assists in the formation of most of the organs of the body (tunica propria, submucosa, interstitial tissue of glands and gland-like organs).

The cellular elements are **lamellar cells, clasmocytes, plasma cells, wandering cells** and **mast cells.**

1. The **lamellar cells** are the chief cells and are usually flattened, stellate elements. Their processes may anastomose with those of other cells. The cytoplasm is usually clear, but a few granules may be present. The nucleus is oval and stains readily. The youngest cells are round; these become spindle-shaped by the development of several processes and by the formation of more processes become stellate in form. They may be pigmented as in the eyeball. In the lymphatic spaces the lamellar cells are flattened elements that constitute the endothelial cells.

2. The **clasmocytes** are irregular, elongated elements that are probably derived from the wandering cells. The cytoplasm is granular and may contain vacuoles. The nucleus is large and oval in form.

3. The **plasma cells** are flattened, elongated, or spheroidal elements that may possess branches; the cytoplasm contains some vacuoles and a number of basophilic granules. The nucleus is usually small and eccentrically placed. These cells are most numerous in the blood-forming and lymphoid organs.

4. The **wandering cells** are merely leukocytes that have wandered in from the blood or lymph.

5. **Mast cells** are large, round elements in which the cytoplasm contains a large number of basophilic granules. These cells are found chiefly in bone-marrow and regions where fat is being deposited. They are probably modified leukocytes.

Pigment cells are seen in the iris, choroid and derma and represent a protection against light. These are really lamellar cells in which the pigment granules are collected in the cytoplasm. This substance may be *melanin*, *hemaglobin* or *fat pigments* (*lipochromes*). The pigment cells of the derma may have ameboid power to a slight degree. In the skin of the frog this pigment is abundant in the stellate cells and the color of the skin can be varied by the distribution thereof. When the pigment granules are forced out of a fresh cell these granules exhibit "Brownian motion."

The intercellular substance is soft and fibrillar in character. The white fibers consist of delicate bundles of fibrils that pass from one bundle to another. The fibers run in wavy bundles that interlace with one another and with the elastic fibers. The elastic fibers are yellow in color and branch. They are not arranged in bundles and are usually thicker than the white fibers.

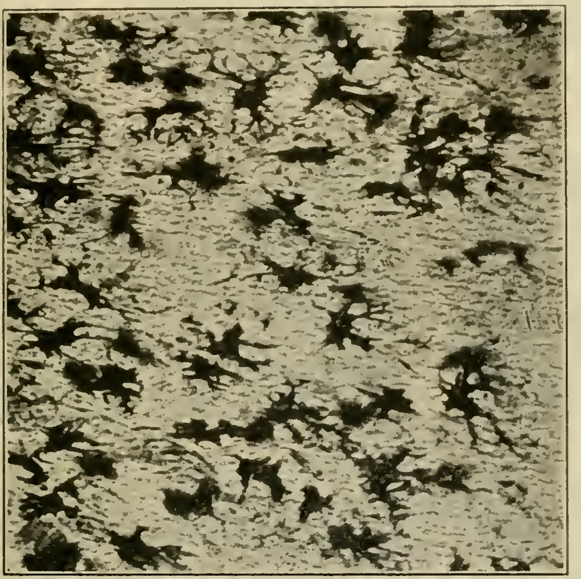

FIG. 55.—PIGMENTED CONNECTIVE TISSUE CELLS FROM THE WEB OF A FROG'S FOOT. (Photographed, Obj. 16 mm., oc. 10 ×.)

2. **White fibrous tissue** is that variety in which the bundles do not interlace but run parallel to one another. It is white, shiny, tough and yet pliable. It is found as the *ligaments*, *fasciæ*, *dura* and *tendons*.

In *fasciæ*, or *aponeuroses* the fiber bundles are arranged in layers that run transversely and longitudinally. The bundles of each layer are parallel to one another and do not interlace. In the *dura* they take different directions and decussate with one another, forming a dense unyielding membrane.

Tendons are *dense* white fibrous tissues, in which all the fiber

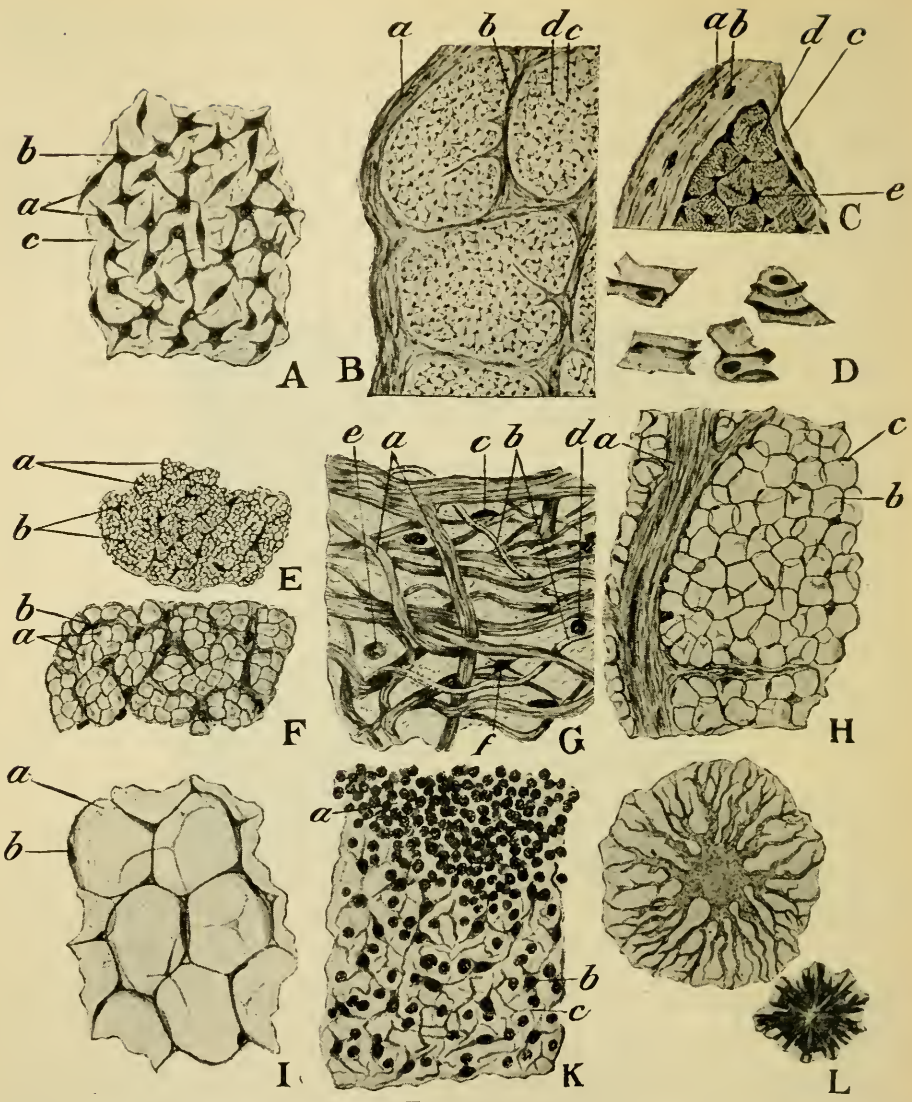

Fig. 56.

A.—Mucous Connective Tissue. *a*, Spindle cells; *b*, stellate cell; *c*, intercellular substance. B.—Cross-section of Tendon. *a*, Epitendineum; *b*, peritendineum; *c*, tendon fasciculi; *d*, interfascicular space. C.—Part of B, highly magnified. *a*, Epitendineum; *b*, cell in *a*; *c*, peritendineum; *d*, tendon fasciculus; *e*, interfascicular space. D.—Tendon Cells from Interfascicular Spaces. E.—Elastic Tissue, Cross-section of Ligamentum Nuchæ. *a*, Elastic fibers; *b*, white fibrous supportive tissue. F.—E highly magnified. *a*, Elastic fibers; *b*, white fibrous supportive tissue. G.—Areolar Tissue. *a*, White fiber bundles; *b*, elastic fibers; *c*, spindle cell; *d*, granule cell; *e*, plasma cell; *f*, stellate cell. H.—Adipose Tissue. *a*, Interlobular connective tissue; *b*, fat cells; *c*, nucleus and cytoplasm and of the cell. I.—H. highly magnified. *a*, Fat cell; *b*, cytoplasm and nucleus of cell. K.—Lymphoid Tissue. *a*, Leukocytes; *b*, stellate connective tissue cells; *c*, reticulum. L.—Pigmented Connective Tissue Cell from a Pike.

bundles have a *parallel* course. The whole structure is surrounded by a sheath of looser tissue, called the *epitendineum*, from the inner surface of which septa are sent in that divide the tendon fibers into large secondary bundles. These latter are further subdivided into primary bundles, each of which is surrounded by a minute sheath, the *peritendineum.* In these sheaths or septa are found the blood-vessels, nerves and lymph channels of the tendon. Although the bundles run parallel to one another they receive slips from and give off slips to neighboring bundles. Still this does not interfere with the important operation of tendon-splicing so useful in surgery. Between the bundles of tendon fibers are seen the peculiar *tendon cells*. These are lamellar cells that are arranged in rows or chains. These cells upon surface view are rectangular, or oblong but upon cross-section they are stellate. This is due to the fact that they are packed in between the bundles and have become moulded by these into their peculiar shape. In denser areolar tissue the lamellar cells may have the same form, due to pressure. The cells are thicker in the middle than at the extremities; the nuclei are oval, lightly stained and may contain one or two nucleoli. In two adjoining cells they will be seen near the line of junction, but in the cells on either side of these, they are separated by nearly the length of the two cells. These cells may possess fine branches that pass in between the tendon bundles. The surface cells of many tendons and aponeuroses may form a continuous layer and their irregular outlines may be brought out with silver nitrate.

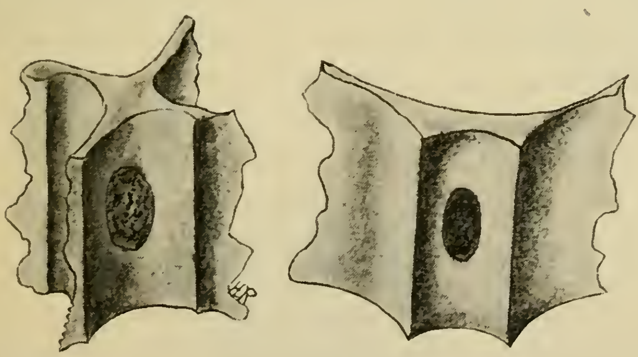

FIG. 57.—TENDON CELLS GREATLY MAGNIFIED. (*Maximow after Tourneau.*)

A few elastic fibers may be found between the larger bundles of tendon fibers. A tendon is very tough and strong and is broken with difficulty. Its strength is greater than a bone of equal diameter.

White fibrous tissue yields gelatin (collagen) upon boiling. The fibers digest in gastric juice and swell when treated with dilute acids. The fibers do not dissolve readily when placed in pancreatin. Picro-fuchsin is a special stain for this variety.

2. **Elastic tissue,** as its name indicates, has the peculiar property of *elasticity.* The cellular elements are comparatively few and of the lamellar variety.

The fibers are yellow in color, refractile, and coarser than those of the white variety, averaging from 1 to 15 microms in diameter. It is one of the components of areolar tissue where the fibers branch. In other places it is found in the form of ligaments and in the blood-vessels it may form a membrane. According to Mall each fiber consists of a delicate sheath surrounding the elastic substance; the latter stains deeply with magenta. In lower animals (quadrupeds) it plays an important part as the ligamentum nuchæ which supports the head. In this ligament the fibers are very heavy and are bound into smaller and larger bundles by white fibrous tissue. In the larger quadrupeds elastic tissue forms an important subcutaneous fascia that assists in supporting the contents of the abdomen.

In man elastic tissue is found in the ligamenta subflava, the crico-thyreoid, thyreohyoid and stylohyoid ligaments, in the vocal cords and as longitudinal bands beneath the mucosa of the trachea and its branches. In the blood-vessels it is found as individual fibers or in the form of Henle's fenestrated membrane.

Elastic tissue is digested by pancreatin and somewhat by pepsin; it is not dissolved by acetic acid. Upon boiling it yields elastin. Special stains are Weigert's elastica and orcein stains.

White fibrous and yellow elastic tissues are poorly supplied with blood-vessels and nerves but are rich in lymphatics.

The *origin* of white fibrous and yellow elastic tissues is still unsettled. According to Meves and others the fibers are formed within the cell by the direct conversion of the exoplasm and processes into fibrillæ. According to Merkel and others both kinds of fibers are formed in the homogeneous intercellular substance by secretions from the cells and not by the direct change of the cytoplasm. Mall regards the intercellular matrix as exoplasm and the cells and processes as endoplasm. He regards the exoplasm as living substance in which the fibrillæ develop.

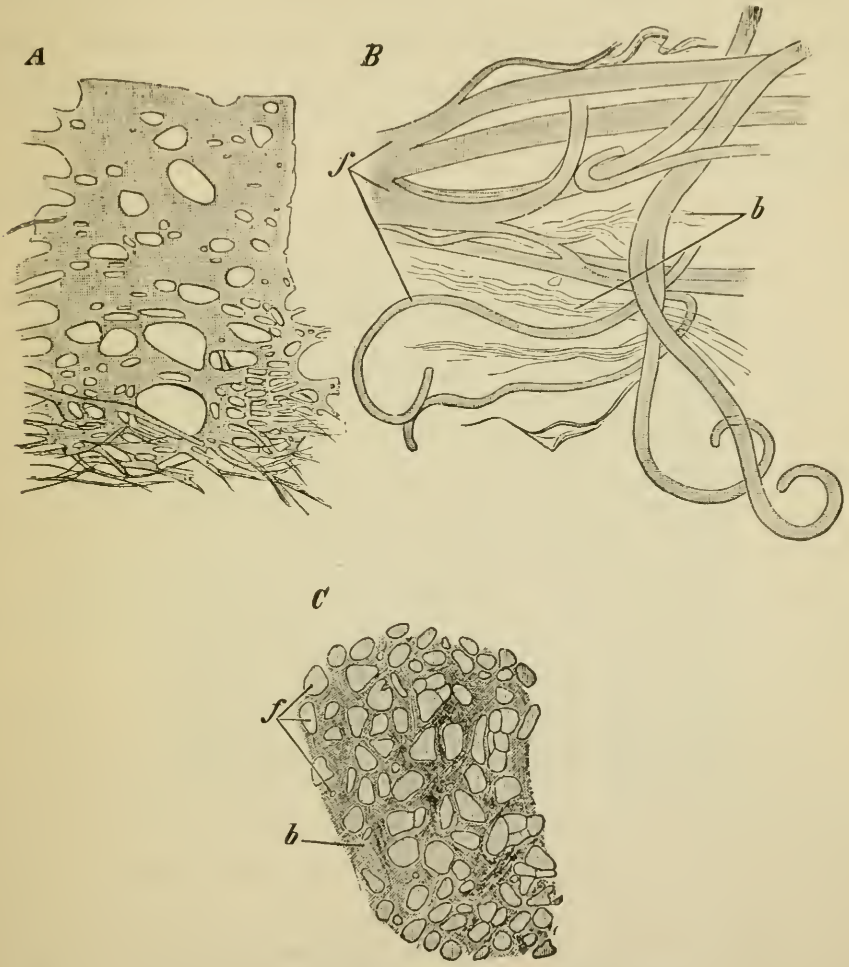

Fig. 58.—Elastic Fibers. (*Lewis and Stöhr.*)

A, Network of thick elastic fibers below, passing into a fenestrated membrane above. From the human endocardium. *B*, Thick elastic fibers (*f*) from the ligamentum nuchæ of the ox; *b*, white fibers. *C*, Cross-section of the ligamentum nuchæ, lettered as in *B*.

Recently it has been found that fibrils develop in organizing blood clots, directly from the fibrin without the assistance or intervention of fibroblasts or leukocytes.

3. **Mucous,** or **embryonic connective tissue** is that variety in which the intercellular substance is semi-fluid. It represents the mesenchyme that differentiates into the other forms. Some consider these as two distinct forms, the *embryonic tissue* occurring in the fetus and during regeneration of connective tissue and in pathologic neoplasms; the *mucous* is considered a fully developed type of connective tissue occurring in the vitreous humor of the eyeball, the pulp of the teeth and as Wharton's jelly of the umbilical cord.

The cells of *embryonic connective tissue* are chiefly of the spindle-shaped type though round and stellate elements are present. The fibers are few in number and fine; they form a network that contains in its meshes the predominating semi-solid ground substance.

In the *mucous connective tissue* the cells are chiefly of the branched lamellar type; in the umbilical cord these cells are numerous but in the vitreous humor they are few in number. The fibers are fairly numerous in the umbilical cord and form layers around the large vessels. In the vitreous humor the fibers are less numerous and tend to form a delicate network. The ground substance is more gelatinous than in the embryonic type and also contains mucin. Both varieties are devoid of blood-vessels, nerves and lymph channels.

In the *pulp of the teeth* the fibrils are most numerous. They form a meshwork for the support of the abundant blood-vessels, nerves and lymph channels of the tooth. The cellular elements are greatly modified, those most important being arranged upon the surface of the pulp in a single layer. These are the *odontoblasts*; they are flask-shaped and from the peripheral surface a number of processes extend into the dentinal tubules. Beneath this layer, toward the center of the pulp is a layer of irregular cells that are supposed to be converted into odontoblasts as these are needed.

5. **Retiform connective tissues,** or **reticulum,** is the supportive tissue of glands and gland-like organs. According to Mall, it is the least differentiated of the mesenchymal tissues. It consists of delicate bundles of fibrils forming a network, in the meshes of which are found the functionating cells of the organ. The cells are chiefly flattened elements that clasp the bundles. Recent investigation

seems to confirm the fact that reticulum is simply a special arrangement of white fibrous tissue.

This tissue is more resistant to those reagents that dissolve the white variety (hydrochloric acid and potassium hydrate) and does not yield elastin upon boiling, but a mixture of gelatin and reticulin, nor is it digested by pancreatin. Among the special stains for this tissue is Mallory's reticulum stain.

Modified.—In these varieties of connective tissue, the intercellular substance varies from liquid (blood) to the hard, unyielding material found in bone and dentin.

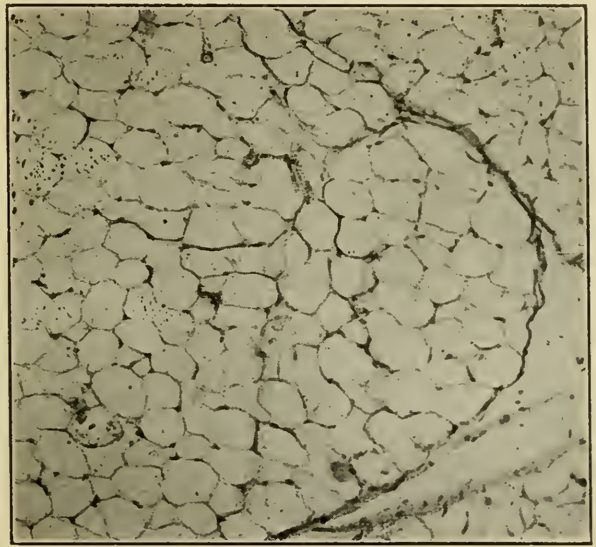

Fig. 59.—Section of Adipose Tissue. (Photograph. Obj. 16 mm., oc. 7.5 ×.)

The *cellular elements* also differ, as will be seen when each variety is discussed.

6. **Adipose tissue,** or **fat tissue** is white fibrous tissue, in which the cells have become repositories for fat globules. These cells are quite numerous, but the stellate shape is lost. It represents a storage of nutritious material as well as a protective structure.

The minute globules unite to form a single large drop that distends the delicate cell-membrane. By this coalescence, the cytoplasm and nucleus of the cell are forced to one side, and are seen as a thin *band,* or *crescent.* The nucleus may contain vacuoles. Fat is supposed to originate from peculiar ovoid granules in the cytoplasm.

Fat cells are spherical, when not closely packed, as the fat is liquid at the body temperature. After death, *margarin crystals* are seen in the cytoplasm. The cells are collected into groups called *lobules*, and these form large masses called *lobes*. Blood-vessels, nerves and lymphatics are present in considerable number. The first named are especially numerous, as there is a close relation between fat deposition and the vascularity of the part.

According to some writers, *fat cells* are specialized connective cells that exist in no other form. This seems doubtful, however, as experiments have shown that when animals are starved, the *spherical*, fat-containing cells return to the *stellate* form as the fat is removed. When this removal occurs the cytoplasm increases, is peculiar in appearance and does not respond readily to the usual stains. These cells still contain a few droplets of fat and are called *serous fat cells*. From this, it would seem that these cells act merely as storage cells.

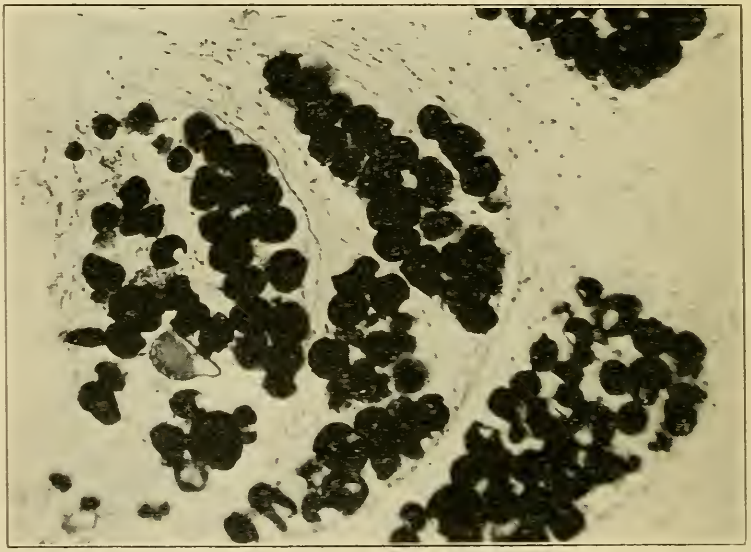

Fig. 60.—Section of Osmicated Adipose Tissue. The fat is black and the fibrous tissue is unstained. (Photograph. Obj. 16 mm. oc. 7.5 X.)

When adipose tissue is studied, after ordinary preparation, merely a network of fibers and cell boundaries is seen. These spaces (fat cells) measure from 40 to 80 microns in diameter. This is due to the fact that the fat has been removed by the alcohol leaving the insoluble white fibrous supportive tissue. In such sections, the nucleated crescents of cytoplasm are readily observable. In sections of *osmicated* fat, the peripheral cells are circular in outline, while the deeper ones are irregular and black, due to the action of the osmic acid, which is a characteristic reagent for fat. *Sudan III*, also used as a test for fat, stains the globules dark red while *cyanin* stains it blue.

Adipose tissue is found widely distributed over the body wherever areolar tissue is found, except in the penis, scrotum, ear, eyelid, lungs and cranial cavity. From the orbit and around the kidneys it never entirely disappears, though death be due to starvation.

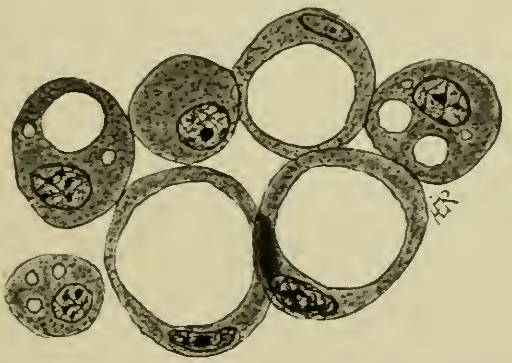

FIG. 61.—CELLS FROM THE SUBCUTANEOUS TISSUE OF A RABBIT SHOWING VARIOUS STAGES OF FAT FORMATION. (*After Jordan and Ferguson.*)

According to E. F. Bell the deposition of fat is preceded by the appearance of a peculiar open network in the areolar tissue. This he calls "preadipose tissue." As fat is being deposited a rich capillary plexus develops.

According to some investigators the formation of fat is due to certain ovoid granular cells that are always seen in the areas of fat deposition. It has also been shown that fat cells can be formed by endothelial cells enclosing free globules of fat.

The first appearance of fat is in the form of very fine granules that are derived from the mitochondria through segmentation. These segments pass through the nuclear membrane in the form of spherical granules, elongate and segment into secondary granules. These granules then liquefy and coalesce into fat droplets

7. **Lymphoid** tissue is a special form of the connective variety consisting of a network of *reticulum*, in the meshes of which are found *leukocytes*, or *white blood-cells.*

These cells are usually the *small lymphocytes*, although varying numbers of the *large lymphocytes* (*hyalin cells*) and *polynuclear cells* are to be seen. For a description of these cells, see **Blood.**

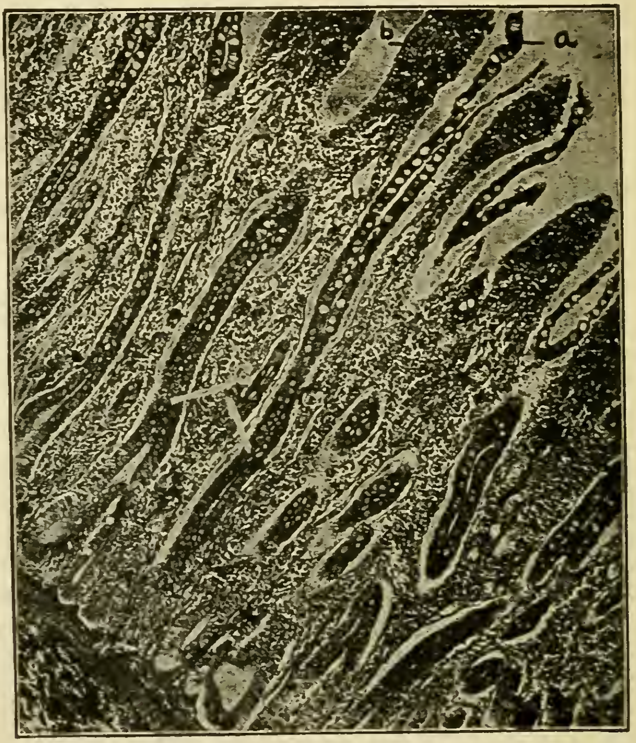

Fig. 62.—Section of the Mucosa of the Jejunum of the Cat.

a, Simple columnar and goblet cell layer separated from the core of the villus *b*; the latter is filled with diffuse lymphoid tissue. *c*, Simple tubular glands with the intervening tunica propria filled with diffuse lymphoid tissue. (Photograph. Obj. 16 mm. oc. 7.5 X.)

For readiness of comprehension, **lymphoid** tissue is divided into four varieties: (*a*) **diffuse**; (*b*) **solitary nodule**; (*c*) **Peyer's patch,** or **agminated nodule**; and (*d*) **lymph node.**

(*a*) **Diffuse lymphoid** tissue is an indefinite collection of leukocytes in an organ. The cells are not especially arranged, neither is there a special supportive tissue present, as in the next two varieties.

The cells may be so numerous as to hide entirely the tunica propria of the structure or the reticulum of the organ.

It is found in the tunica propria of the alimentary, respiratory and urinogenital tracts, and the cells are merely scattered between the bundles of white fibrous tissue. It forms the medulla of the thymus body, and the bulk of the tonsil and spleen, and is transient in character.

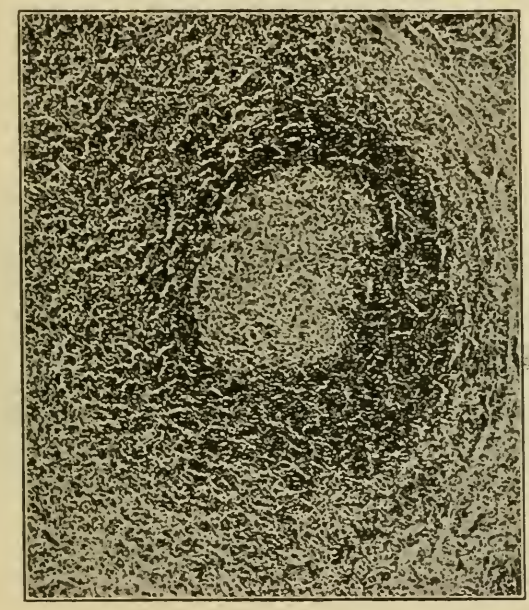

Fig. 63.—Solitary Nodule of the Spleen of a Monkey. The light area is the germinal center. The nodule is surrounded by diffuse lymphoid tissue. (Photograph. Obj. 16 mm., oc. 7.5 ×.)

(*b*) **Solitary nodules** are small, dense collections of lymphocytes. The supportive tissue is said to be reticulum, the meshes of which are larger in the germinal center than at the periphery. Blood-vessels are inconspicuous; although the outline may be slightly irregular, it is sharp. Each nodule usually shows a lighter center in which the cells are fewer and younger. This is called the *germinal center*, and here the new cells are formed by karyokinetic division. As the new cells are formed the excess cells are crowded to the periphery of the nodule, forming there a denser mass giving this area a darker appearance.

Soiltary nodules are found in the alimentary and respiratory tracts, the spleen and tonsil. They, like the diffuse variety, are transient structures.

(*c*) **A Peyer's patch** is a more or less regular collection of solitary nodules sharply outlined from the surrounding tissue and 1 to 5 cm. long. Each patch consists of ten to sixty solitary nodules, each of which usually shows a *germinal center*.

Each nodule may be partially or completely surrounded by a thin capsule of white fibrous tissue, although usually the nodules merge more or less into one another. They are located in the submucosa of the ileum opposite to the attachment of the mesentery.

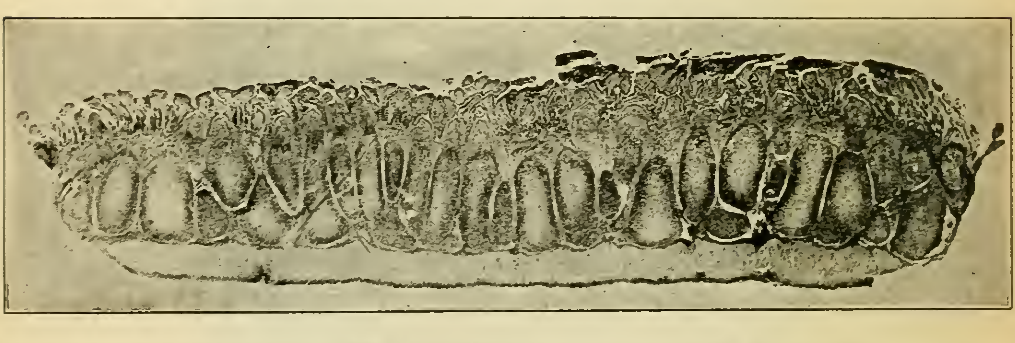

Fig. 64.—An Agminated Nodule of the Ileum of a Cat. (Photograph. Obj. 48 mm.)

Some state that they are also found in the jejunum. The long axis is directed parallel to the long axis of the bowel. They are visible to the unaided eye. Although they are said to be limited to the submucosa, more commonly they are seen invading the mucosa, having broken through the muscularis mucosæ. Usually in those areas, where the nodules approach the epithelial surface, the glands are absent. At the edge of the nodules the glands are seen arranged in the form of a circle. Often the villi over such an area are likewise absent.

(*d*) **Lymph nodes (lymph glands)** are small, bean-shaped bodies interposed in the pathways of the lymphatic vessels. As they are closely related to the **lymphatic system,** their structure will be there considered.

CARTILAGE

8. **Cartilage** is a firm substance that is elastic, yields to pressure and is readily cut with a sharp knife. It is characterized by the presence of a solid intercellular substance and the cells differ materially from those of the preceding varieties of connective tissue. **Three varieties** are found in man: **hyalin, white fibrocartilage** and **yellow elastic.** The general structure will first be considered under *perichondrium*, *cells* and *intercellular substance.*

The *perichondrium* is a fibrous sheath that surrounds cartilage and gives rise to its cellular elements. It is composed of white fibrous tissue, and is divided, functionally, into two parts. This division is not apparent under the microscope, as the layers merge into each other. The *outer* part is the *fibrous* layer, and contains few cells. The *inner portion*, or *chondrogenetic layer*, is rich in cells that are not of the stellate type, but flattened and elongated, or spindle-shaped. These are the *chondroblasts*, which become cartilage cells. Some blood-vessels also are present. Bundles of fibers from the perichondrium pass into the matrix.

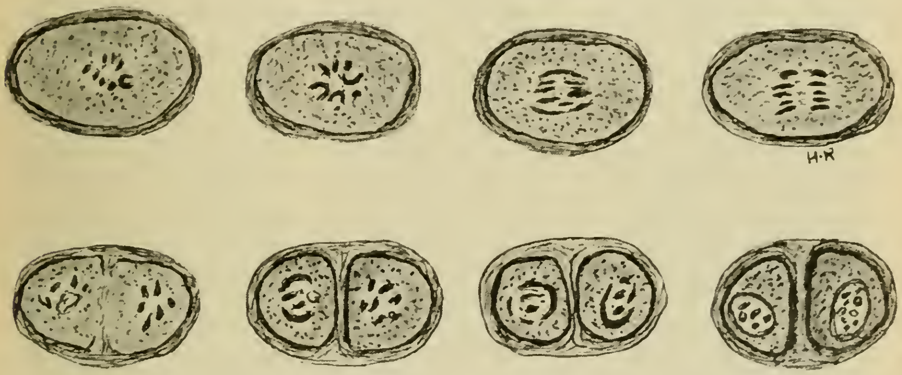

FIG. 65.—REPRODUCTION OF CARTILAGE CELLS. (*After Schleicher.*)

The *cartilage cells*, or *chondroblasts*, vary in the different portions of the cartilage. Just beneath the perichondrium, they are flat and thin, indicating an early stage. Toward the center, they gradually become broader until, finally, they are oval or round in form. Each cell is rich in cytoplasm, which contains one or more vacuoles, often glycogen and occasionally fat droplets. The nucleus is spheroidal, appears granular and may contain one or more nucleoli. Each cell lies in a cavity of the matrix and usually fills this. There may be a space (*lacuna*) due to shrinkage of the cell. The boundary of the cavity is the *capsule;* this resembles the matrix and is firmly attached to it. Sometimes the capsule stains more deeply than the matrix. The capsule is a product of secretion of the cell and represents the exoplasm. It is cast off, as a rule, each time the cell divides. Each cell may be individual or several may occupy one cavity. This is due to the fact that each new cell did not form a capsule for itself after division. The apposed sides of these cells are flattened by pressure of one against the other.

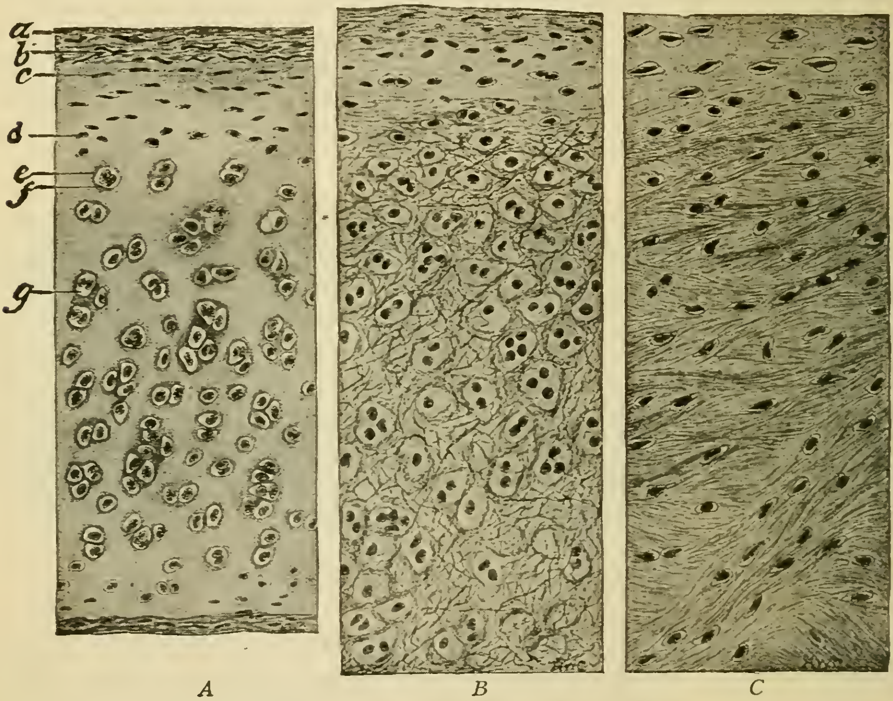

FIG. 66.—SECTIONS OF CARTILAGE.

A.—HYALIN CARTILAGE. *a*, Fibrous layer of perichondrium; *b*, genetic layer of perichondrium; *c*, youngest chondroblasts; *d*, older chondroblasts; *e*, capsule; *f*, cells; *g*, lacuna. B.—ELASTIC CARTILAGE. C.—WHITE FIBROCARTILAGE.

The *intercellular substance* varies. In the hyalin variety it is apparently homogeneous; white fibrocartilage is composed mainly of white fibrous tissue; in yellow fibrocartilage it is composed of yellow elastic fibers.

Hyalin Cartilage.—In this variety the *cellular elements* are as above. They are quite numerous and close together just beneath the perichondrium. Farther in they are larger and more widely separated and several may be found within one capsule.

The *intercellular substance*, or *matrix*, is apparently homogeneous. Upon careful study, however, and often without treatment with special reagents, it shows a fibrillar character; in this fibrillar meshwork is seen the ground substance, which is homogeneous. This fibrillar structure is especially noticeable in young cartilages. The ground substance is formed by the fusion of the castoff capsules and usually responds to mucin stains.

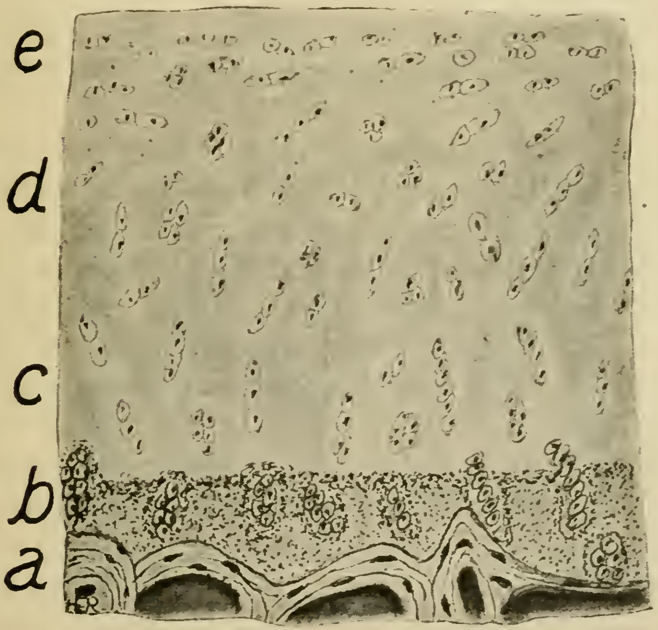

FIG. 67.—A VERTICAL SECTION OF ARTICULAR CARTILAGE.
a, Bone; *b*, calcified cartilage; *c*, perpendicular groups; *d*, irregular groups; *e*, horizontal groups, parallel to the surface. (*After Schäfer.*)

Articular Cartilages.—In these the cells are smaller and arranged in short rows. At the perichondrium the rows are parallel to the surface of the bone. The matrix is granular and after maceration, under pressure it separates into fibrils that run vertical to the surface. The perichondrium blends with the periosteum.

Hyalin cartilage is found covering articular surfaces of bones, as the costal, nasal, tracheal and most of the laryngeal cartilages.

It precedes, with a few exceptions, all the bones of the body, and may ossify in old age.

White fibrocartilage consists of islands of the *hyalin* variety, separated by an *intercellular substance* made up of delicate, wavy bundles of white fibrous tissue that have a parallel course. The amount of hyalin matrix varies in these cartilages. In the *intervertebral discs* the cartilage cells are more numerous toward the central pulp. In the *symphysial cartilages* the cells are more numerous at the surface attached to the bone.

This variety is not very abundant but is widely scattered. It is found as *marginal cartilages* (deeping joint cavities); as the *intervertebral discs;* as *intra-articular cartilages; lining grooves in bone* where tendons move and occasionally as *sessamoid fibrocartilages* in tendons.

Yellow fibro- or **elastic cartilage** is that variety in which the intercellular substance is composed of *elastic fibers.* The elastic tissue forms a meshwork in which the hyalin islands are found.

It is practically *hyalin* cartilage in which the hyalin matrix has been replaced by *elastic tissue.* The cartilage cells are found in small groups, surrounded by only a small amount of the hyalin substance. This variety never ossifies or calcifies, and is to be looked for in regions where elasticity is required, as in the epiglottis, ear, Eustachian (auditory) tube and small laryngeal cartilages.

Cartilage contains few or no *blood-vessels,* except in the perichondrium, and during the developing stage. *Lymph channels* are said to be absent, so that its nutrition is not of a very high order.

Upon heating cartilage to 120°C. in a hermetically sealed tube *chondrin* is obtained. This will not dissolve in either alcohol or cold water. It is precipitated by acetic acid, insoluble in an excess of this but soluble in some mineral acids.

When cartilage begins to develop the polygonal cells of the mesenchyme become clearer and the nucleus more distinct. The tissue immediately surrounding the cells also becomes clear and constitutes the cohering capsules of the adjacent cells and represents the matrix. If the matrix remains in this condition permanently it is called *parenchymatous.* Glycogen appears early in the cytoplasm of these cells. This is followed by the rapid increase in size and multiplication of the cells with an attendant increase in the matrix. As the cells reproduce the old capsules are cast off and blend with the matrix of which they soon become an indistinguishable part. In each succeeding division more cells are formed, more capsules are cast off and the matrix thus becomes increased in quantity. As a result of the latter condition the cells come more widely separated. According to Kölliker the capsule is secreted by the cell, but according to M. Schultze it represents the superficial cytoplasm (exoplasm) of the cell.

In elastic cartilage the matrix is at first entirely hyalin. Gradually fine, albumoid granules appear in the matrix close to the cells and gradually extend outward toward the perichondrium. From these granules the elastic fibers are derived. The fibers of the white fibrocartilage are said to appear at the same time as the matrix but in what manner is not exactly known.

Cartilage regenerates. When a cartilage is cut the wound is healed by white fibrous tissue. Later this is gradually transformed into cartilage. Costal cartilages, when fractured, heal by a fibrous connection often. This is usually very dense at its circumference and ossification may later occur in this dense tissue.

9. **Bone** is the most highly differentiated of the connective tissues. It is characterized by the presence of a very hard, unyielding intercellular substance that has a characteristic arrangement.

Bone is composed of *inorganic* (66 per cent.) and *organic salts* (34 per cent.); the *former* are soluble in mineral acids, by which they may be removed and the tissue cut. The *latter* are removed by burning, after which process the inorganic substance remains as a porous mold of the bone. The earthy material gives hardness and rigidity, while the animal material gives tenacity and elasticity.

Bones, like cartilage, are surrounded by a fibrous sheath, the *periosteum,* beneath which is the *bone substance* proper; the latter consists of *cells* and *intercellular substance.*

The **periosteum** of young bones consists of *three layers, fibrous, fibroelastic* and *osteogenetic.*

The *fibrous layer* is composed of coarse bundles of white fibrous tissue that serve to connect the periosteum to the surrounding tissues.

The *fibroelastic layer* consists of more delicate bundles of white fibrous and especially elastic tissues.

The *inner*, or *genetic*, layer is rich in cells and capillaries and contains only sufficient white fibrous tissue to support these. These cells are the *future osteoblasts* that secrete the osseous tissue. From its inner surface, it sends in bundles of fibers that pierce the layers of bone at right angles, and bind them together. These are *Sharpey's fibers*. Some of these are derived from the tendons inserted into the periosteum. In addition there are the *lamellar fibers*. These are delicate bundles of white fibrous connective tissue that pass through the various lamellæ some at right angles and others obliquely. Some of the fibers are elastic. In the adult, after growth ceases, the vessels in the innermost layer of the periosteum are reduced in number and the osteoblasts are only sufficient in number for the purpose of regeneration of the bone. The fibroelastic layer becomes correspondingly thicker.

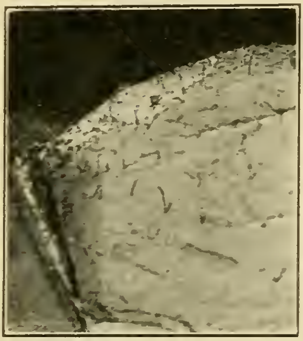

FIG. 68.—A PREPARATION OF THE DURA SHOWING SHARPEY'S FIBERS, THE HAIR-LIKE PROJECTIONS ON THE DURA. (*Photograph.*)

The periosteum not only gives rise to the osteoblasts but also serves for the support of blood-vessels, nerves and lymph channels and for the attachment of muscles, tendons and ligaments.

The *cells* are all of the irregular stellate type, and consist of flattened bodies and short processes that extend into small canals, to be described later. The cytoplasm is not very abundant, and the nuclei are oval, and often vesicular. No doubt but that the osteoblasts assist in the nutrition of the bone by modifying the nutritive elements derived from the blood and distributing it to the osseous tissue through the lacunæ and canaliculi. These latter structures represent the cell spaces of the ordinary connective tissues. The osteoblasts are homologous to the lamellar cells of areolar tissue.

The *intercellular substance* is hard and resistant but elastic. It consists of osseous material that is secreted by the cells, and is peculiarly arranged in the compact variety. It contains spaces, or *lacunæ*, from which extend minute canals, or *canaliculi*. Beside

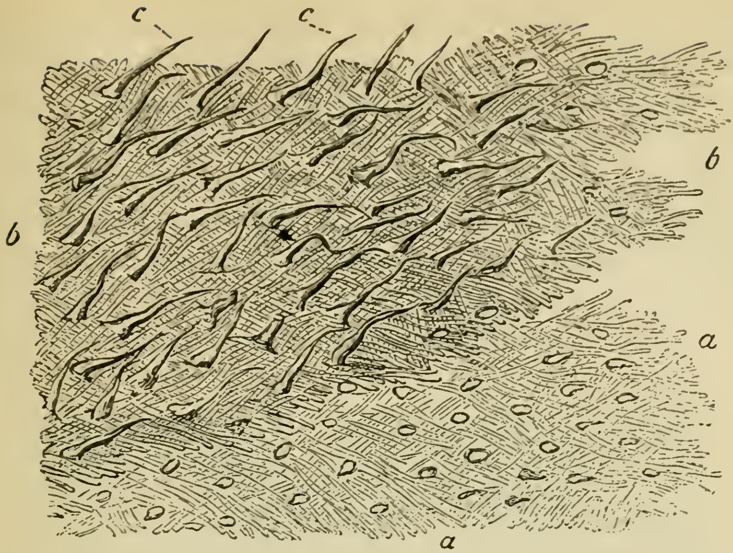

FIG. 69.—LAMELLÆ STRIPPED FROM A DECALCIFIED PARIETAL BONE. (*Sharpey.*) *a, a,* Lamellæ exhibiting decussating fibers with openings for the perforating fibers. *b, b,* Stripped lamellæ with the perforating fibers *c, c.*

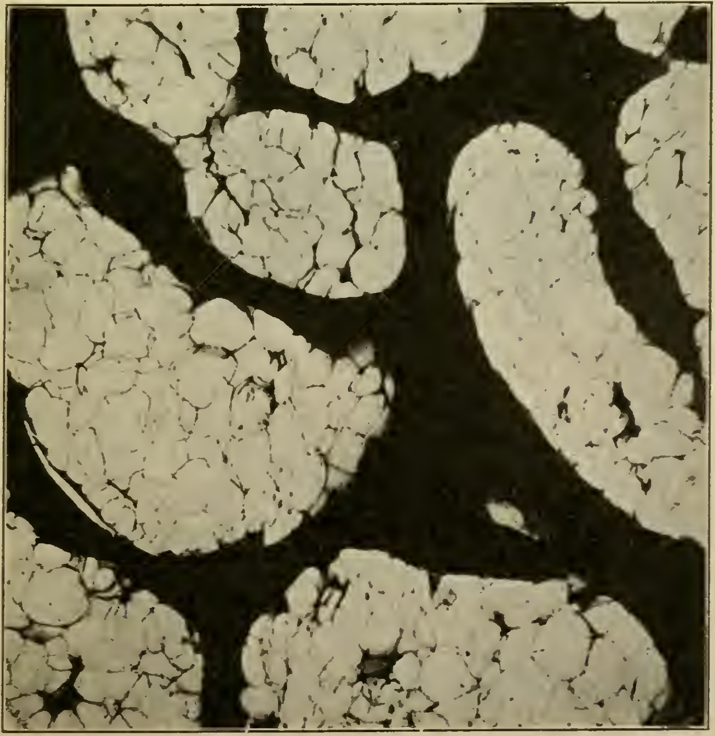

FIG. 70.—A SECTION OF CANCELLOUS BONE SHOWING THE MARROW RETICULUM AND ADIPOSE TISSUE BETWEEN THE BONY SPICULES. (Photograph. Obj. 16 mm., oc. 5 X.)

these, there are a great number of canals that vary in length and diameter. These are the *Haversian canals.*

There are two varieties—**cancellous,** or **spongy,** and **compact,** or **solid.**

Cancellous bone consists of spicules and lamellæ forming a network resembling a sponge, or lattice. The lamellæ run in the direction of the greatest strain. The spicules have a lamellar structure and contain delicate Haversian canals surrounded by a few thin, concentric lamellæ; in addition there are little spaces called lacunæ. In the living, or recent condition these spaces are occupied by osteoblasts, the bone-forming cells.

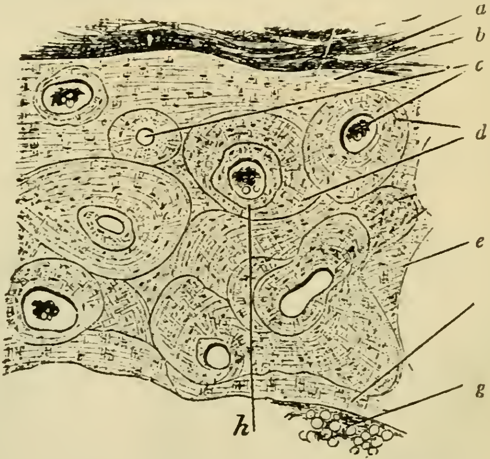

FIG. 71.—CROSS-SECTION OF HUMAN COMPACT BONE.

a, Periosteum; *b,* peripheral lamellæ; *c,* Haversian canals; *d,* lacunæ; *e,* interstitial lamellæ; *f,* perimedullary lamellæ; *g,* marrow; *h,* Haversian lamellæ. (*Stöhr's Histology.*)

This variety is found around the medullary cavity and in the extremities of the long bones, and forming the central portion of the flat, irregular and short bones. The meshes of the network are covered by the *endosteum* and are filled with marrow.

Compact bone has a characteristic structure. The osseous matter is arranged in layers, or *lamellæ,* between which lie the *lacunæ.* There are four varieties of lamellæ: (*a*) *periosteal, peripheral,* or *circumferential;* (*b*) *Haversian,* or *concentric;* (*c*) *intermediate, ground,* or *irregular;* and (*d*) *perimedullary,* or *internal.*

(*a*) The *peripheral, periosteal,* or *external* lamellæ are those formed directly from the periosteum. They are few in number, and several are required to complete the circumference. Between them are a number of irregular spaces, *lacunæ*, from which little canals extend, the *canaliculi*. The external layer has a number of small depressions called *Howship's foveæ* or *lacunæ*. These are occupied by large bone-destroying cells called *osteoclasts*. Haversian canals are not present, but larger canals, containing blood-vessels from the periosteum, are seen. These are *Volkmann's canals*, and they communicate with the Haversian canals farther in.

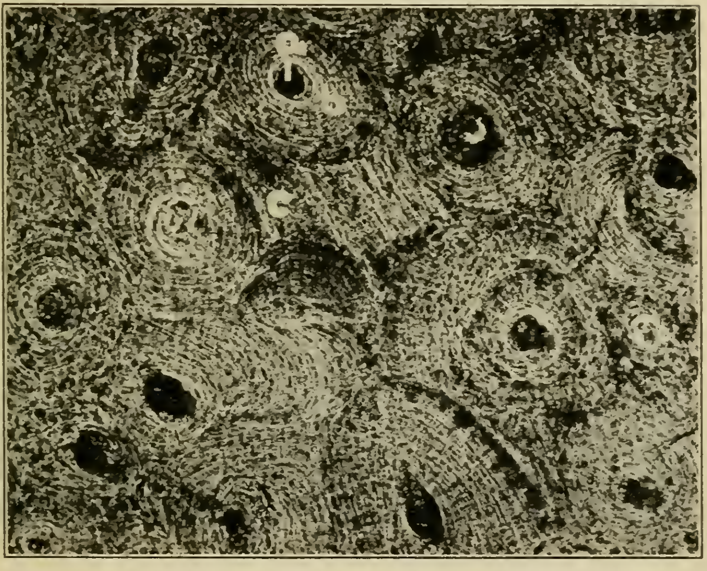

FIG. 72.—CROSS-SECTION OF COMPACT BONE (GROUND).
a, Haversian canal; *b*, Haversian lamellæ; *c*, intermediate lamellæ. (Photograph. Obj. 16 mm., oc. 7.5 ×.)

(*b*) The *Haversian* lamellæ, which are probably the most numerous, are thin, cylindric layers concentrically arranged around a small central canal called the *Haversian canal*. These layers are separated in places by the lacunæ, and pierced by the canaliculi. The lamellæ of a system are parallel to one another, but the different systems usually run at various angles.

An *Haversian system* consists of the lamellæ, canal, lacunæ and canaliculi.

The *Haversian canals* are occupied by blood-vessels, nerves and lymphatics. Those nearest the marrow cavity are the largest, contain marrow and communicate with the marrow cavity. The short canals are generally parallel to the long axis of the bone, anastomose freely with one another and measure 25μ to 125μ in diameter.

(*c*) The *intermediate, interstitial,* or *irregular* lamellæ lie between the Haversian systems, and are irregular in size and form. They are the remains of Haversian and periosteal lamellæ, altered by the growth of the bone in diameter. No canals are found here, but lacunæ and canaliculi are present between the lamellæ.

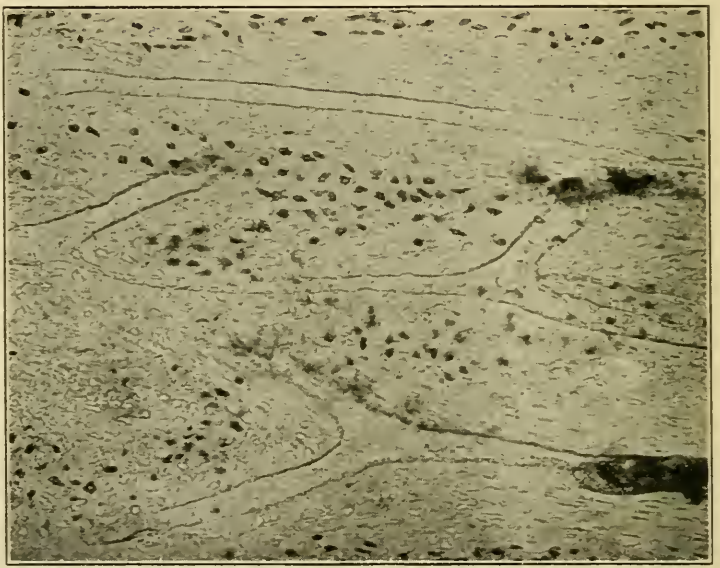

Fig. 73.—Longitudinal Section of Compact Bone (Ground) Showing Branching Haversian Canals. The irregular dark spots are the lacunæ. (Photograph. Obj. 16 mm., oc. 7.5 ×.)

(*d*) The *perimedullary,* or *internal,* lamellæ are not very regular, and are found surrounding the medullary, or marrow cavity.

The *lacunæ* are small, flat, irregular spaces found between the various lamellæ throughout the bone, and occupy a portion of each of the adjacent lamellæ, and do not lie in one alone. Each space measures from 13μ to 31μ in length, 6μ to 14μ in width and 4μ to 9μ in depth. The walls of the lacunæ and canaliculi are more resistant to acids than the remainder of the osseous tissue. These spaces are said to be lined by a delicate membrane and they contain the osteoblasts.

Extending in all directions, are small canals, or *canaliculi* (1 to 2 microns in diameter), that communicate with those of other lacunæ, so that a series of intercommunicating spaces results. Those lacunæ lying nearest the Haversian canals, communicate with them, but the peripheral ones of a system do not communicate, to any great extent, with those of the interstitial lacunæ. The canaliculi serve as supports for the processes of the osteoblasts.

The compact portions of the extremities of bones contain no Haversian systems and no large lacunæ so that pressure can more readily be borne. Vessels do not enter the bone here.

The *flat*, *short* and *irregular bones* consist of a thin shell of compact bone covering a mass of cancellous bone that constitutes the bulk of these bones. Where the bones are thin, or have small processes, no cancellous bone is present.

The **medullary cavity,** which contains the nutrient marrow, is a large space, in the shafts of the long bones; it is lined by the *endosteum* which is analogous in structure and function to the periosteum; it also constitutes a covering for the marrow.

The **marrow** is of two varieties, *red* and *yellow.* The *red* marrow is found in the marrow cavities and in the cancellous bone of the extremities of the long bones and in the cancellous tissue of the flat and irregular bones, in *young persons;* in *adults* the marrow in the marrow cavities becomes yellow. The difference is due to the presence of a great deal of fat in the yellow marrow, whereby the color becomes changed. It is not a blood-making tissue as the cellular elements are few or may be entirely wanting. In disease, however, it may again become red.

The **red marrow** consists of a delicate network of reticulum, derived from the endosteum, supporting a dense capillary plexus, nerves and lymphatics and a number of different cells. These cells are (1) *myelocytes*, or *marrow cells;* (2) *nucleated red blood cells*, or *erythroblasts;* (3) *erythrocytes;* (4) *white blood cells*, or *leukocytes;* (5) *myeloplaxes;* (6) *osteoclasts;* (7) *osteoblasts;* (8) *fat.* The red bone marrow is the most important red cell-forming tissue in the body throughout life.

1. The **myelocytes** are large nucleated masses of granular cytoplasm that resemble the leukocytes of the blood. The *granules* of the cytoplasm are in some of these cells fine and neutrophilic or acidophilic in reaction; in other cells they are coarse and basophilic in reaction. The *nucleus* is usually large, oval and lobulated and the chromatin small in quantity. Some of these cells are *ameboid* and *phagocytic;* the latter contain reddish-brown pigment granules that are probably converted hemoglobin. Some consider these cells as derivatives of the blood lymphocytes and others maintain that they are the ancestors of the oxyphils and basophils of the blood.

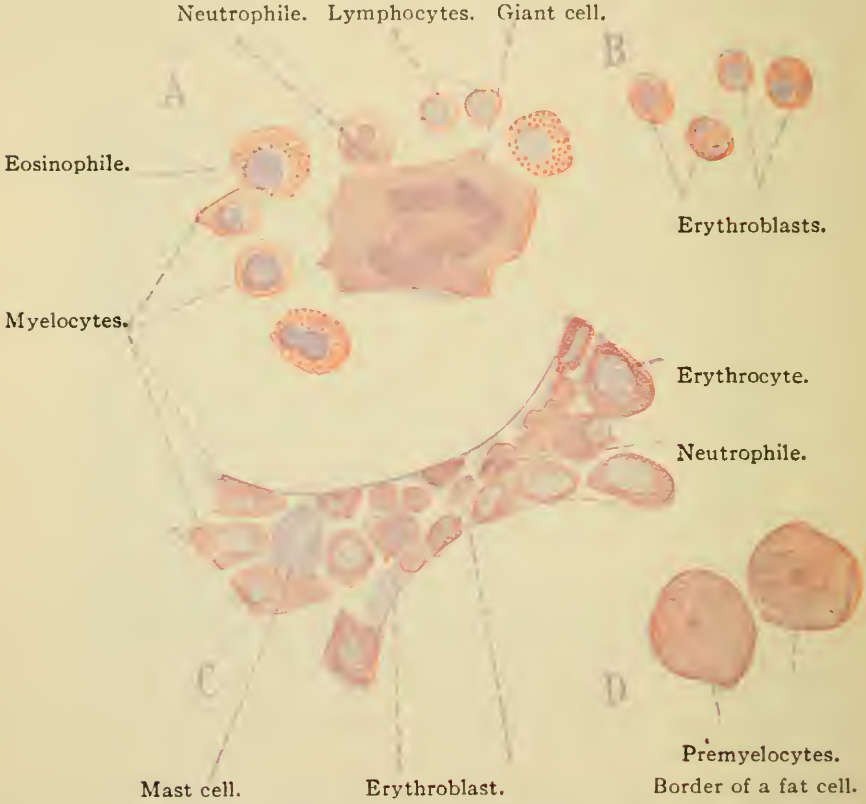
Neutrophile.
Lymphocytes.
Giant cell.
A
B
Eosinophile.
Erythroblasts.
Myelocytes.
Erythrocyte.
Neutrophile.
C
D
Premyelocytes.
Mast cell.
Erythroblast.
Border of a fat cell.

FIG. 74.—ELEMENTS OF HUMAN BONE MARROW. (*Lewis and Stöhr.*)
A, From the femur at 10 years. B, from a cervical vertebra at 19 years. C, from the femur at 77 years. D, from a rib at 59 years.

2. The **erythroblasts** differ from the erythrocytes in that each contains a nucleus and this may show mitotic figures. These cells

vary somewhat in size but are seldom over 9.5μ in diameter. By the loss of the nucleus these cells become the erythrocytes, or normal red blood cells.

Two varieties are described: The *erythroblasts* that possess a nucleus rich in chromatin network and poor in hemoglobin. These cells gradually change to the *normoblasts* in which the nucleus shows no chromatic network and the cytoplasm is rich in hemoglobin.

Some classify all of the nucleated red cells as *erythrocytes* of which the *megaloblast* is the original cell, the *normoblasts* and *erythroblasts* modifications, which by the loss of the nucleus become the normal red cells or *erythroplastids* as they call them.

3. **Erythrocytes** (**erythroplastids**) are the preceding cells that have lost their nuclei and are ready to enter the blood-stream. The manner in which the nucleus is lost is still questionable. Some state that the entire or fragmented nucleus is extruded (*karyorrhexis*); others believe that the nucleus is absorbed (*karyolysis*); Emmel has found that the red cell of the pig is formed by *budding*.

4. The **leukocytes** are of different varieties of which the first three varieties below given are the most numerous.

(*a*) The *finely granular oxyphil* (*polymorphonuclear neutrophil*) is 7.5 to 10μ in diameter. There are several stages of these cells, the younger showing a centrosome and nuclei that contain only a little chromatin and fewer modifications of shape and the older ones that have a dense chromatic network and more varieties of nuclear shapes. The younger cells are said to be capable of cell division to a slight extent and the older ones not at all.

(*b*) *Eosinophils* are of the same size as the preceding. They differ from these, however, as the granules in the cytoplasm are much larger in size but fewer in number and strongly acidophilic in reaction. The younger cells contain a centrosome and are capable of division but the older ones are not.

The *oxyphil* and *neutrophil granules* are probably *intracellular in origin*. They seem to arise from the chromidia extruded from the nucleus and so are originally basophilic in reaction; by chemical changes within the cytoplasm they change their character. Weidenreich believes that these granules represent hemoglobin from the disintegrating red cells as the latter are numerous in the marrow and spleen.

(*c*) *Basophils* (*mast cells*) are believed to be formed in the red marrow. The nucleus varies in shape and the cytoplasm contains a number of large, coarse, basophilic granules. They are also found in areolar tissue where they probably end their existence. Some claim that these cells are normally found in the blood-stream but this is doubtful. In certain diseases, however, they increase in number in the marrow and spleen and are also found in the blood under those conditions.

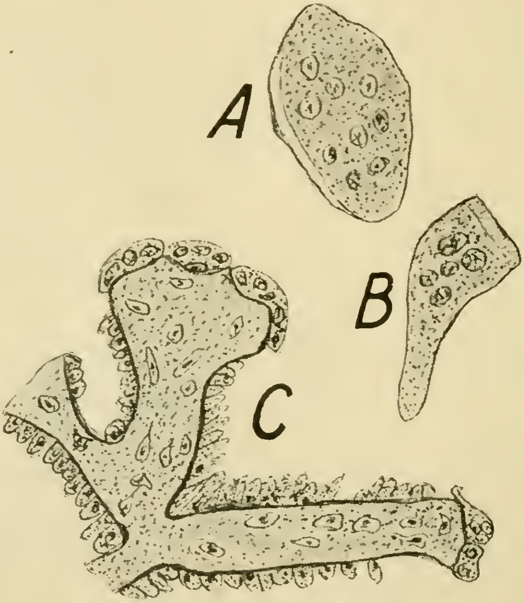

FIG. 75.—OSTEOCLASTS.

A. Ordinary osteoclast. *B*, one showing a striated border. *C*, a bone trabecula from the mandible of a calf embryo with the osteoblasts at the ends causing absorption and osteoblasts covering the sides and depositing bone. (*After Kölliker.*)

(*d*) The *lymphocytes* are the smallest of the leukocytes, measuring from 5μ to 7.5μ in diameter. The cytoplasm is small in quantity, does not stain deeply and may be basophilic in reaction. The nucleus is large and nearly spherical in form and the chromatin stains readily. These cells are not numerous and while some are developed here most of this type are formed in the lymphoid structures and organs.

(*e*) The *hyalin cells* (*large lymphocytes*) are the largest leukocytes measuring from 11μ to 15μ in diameter. They are said to be derived from the lymphocytes which they resemble. The nucleus, however, does not respond so well to stains so that the whole cell has an hyalin appearance, hence the name.

A more detailed description of these leukocytes will be found under **Blood.**

5. **Osteoclasts** are very large spheroidal, or flattened cells. Their outline is regular and the granular cytoplasm contains two to ten or more clear round nuclei. These cells are numerous in developing and regenerating bone. The side of the cell attached to the bone is often striated. They are also found in connection with the roots of the milk teeth. They are of great importance in bone destruction from which the name osteoclast is derived. They are capable of ameboid movements and are phagocytic.

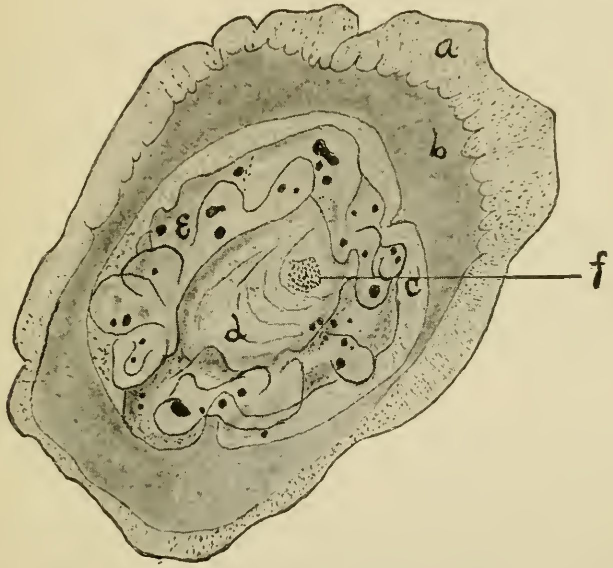

FIG. 76.—GIANT CELL OF BONE MARROW SHOWING MULTIPLE CENTRIOLES AT *f*. *a*, *b*, *c*, *d* represent the different zones of cytoplasm; *e*, nucleus. (*Reference Handbook of the Medical Sciences. After M. Heidenhain.*)

6. **Myeloplaxes,** or **megakaryocytes** are also giant cells 30μ to 100μ in diameter. The cytoplasm is granular and the large single nucleus is usually horseshoe-shaped or annular. It contains a large

number of nucleoli and a number of centrioles. It is ameboid but not phagocytic. The blood platelets are said to be derived from their segmented pseudopodia.

7. **Osteoblasts** occur at the periphery of the marrow along the endosteum.

8. **Adipose tissue** is seen in red marrow. During adolescence it gradually increases in the marrow cavities of the long bones and so replaces the bulk of the red marrow, forming the *yellow marrow*. As the cellular elements in this are very few it is no longer an hematopoietic structure.

The **blood-vessels** of bone are very numerous. In the *flat, irregular* and *short bones* many vessels penetrate the superficial compact bone and enter the spongy parts branching into many channels that supply the marrow and osseous tissue. Another set of vessels in the periosteum supplies the supperficial compact bone and the underlying spongy bone. In the *long bones* the superficial portions are supplied by the periosteal vessels. These penetrate the outer compact bone, through Volkmann's canals, and branches pass in to the Haversian canals. At the extremities these periosteal vessels send branches into the superficial portion of the spongy bone also. The marrow and the deeper parts of the bone are supplied by what is commonly called the *nutrient vessel*. This is usually one large trunk that enters at the nutrient canal of the diaphysis, passes to the marrow and forms here branches that proceed toward each extremity. These latter branches give rise to vessels that supply the marrow, the compact bone and the cancellous bone. The branches of the two systems anastomose freely. The **veins** start in wide venous capillaries that empty into large venous channels that, in cancellous bone run in bony canals separate from those of the arteries. These veins are thin-walled, possess no media and are valveless. They issue from the bones through numerous large openings. The circulation in the red marrow of mammals is believed to be an open one. The walls of the venous capillaries are supposed to be incomplete permitting the passing of the cellular elements of the marrow into the blood-stream. This seems doubtful for in this case there would be nothing to prevent the abnormal constituents, as myelocyte, myeloplaxes, osteoclasts, etc., from entering the blood-stream. The blood coming from the marrow contains more than the usual number of leukocytes.

Lymphatics occur in the periosteum and in the Haversian canals in which they may entirely surround the blood-vessels. The lymph passes into the denser parts through the lacunæ and canaliculi.

The **nerves** accompany the arteries which they supply. Whether or not any come into relation with the bone cells is not known. In the periosteum nerves supply the blood-vessels and also sensor organs, Pacinian bodies, are found.

Development of Bone.—Bone is not a *primary*, but a *secondary* tissue. It is preceded by cartilage or by fibrous tissue. Bone developed from hyalin cartilage is called **endochondral,** while that developed in fibrous tissue is referred to as **intramembranous** bone. The area where bone-formation begins is called the *center of ossification.*

Endochondral bone formation is the process by which the hyalin cartilage is converted into **spongy** bone. It is, in reality, a combined process, for so soon as the spongy bone is formed, this is changed to the *compact* variety by the *intramembranous*, or *periosteal method.*

When **ossification** begins, the cartilage cells in that vicinity begin to multiply rapidly, increasing in size at the expense of the matrix, which shows evidence of calcareous deposits above and below this area; the other cells arrange themselves in rows parallel with the long axis of the bone. This grouping of the cells is probably due to the course of the lymph stream and the pressure exerted by the groups upon one another. Multiplication is most rapid in the center of the area, and, as a result, the new cells are unable to form new capsules for themselves; in consequence, a large number are seen in one space called a *primary areola*, or *marrow space.* The cells then become vesicular and shrunken, do not respond readily to stains and show signs of degeneration. In the cartilage between these spaces, calcareous material is deposited, and the cells above and below arrange themselves into parallel rows. The cells within the areolæ either *disappear* or become *osteoblasts*, and *osteoclasts* (Stöhr and others believe that all disappear). The latter, 45 to 90 microns long and 30 to 40 microns wide, dissolve the cartilaginous and calcareous partitions between the spaces. As a result of the latter, larger spaces are formed, and these are the *secondary areolæ.* The *osteoblasts*, lay down a thin layer of osseous tissue upon the remaining partitions, so that, at first, these consist of a core of calcific material covered by a thin veneer of true bone. As the process continues, the calcareous matter is entirely removed and is replaced by bone.

While these changes have been in progress, the *perichondrium* has become the *periosteum,* which now forms *osteoblasts.* These, with trabeculæ of the periosteum and blood-vessels, pass inward toward the center of ossification, and enter the areolæ. This *vascularization* forms the first marrow. The blood-vessels pass upward and downward from the center, following the process of calcification. Gradually, the delicate rod of cartilage is converted into a rod of spongy bone. The articular portions are separated from the shaft by an interposed disc, the *epiphyseal cartilage.*

Periosteal bone formation now begins. Upon the *inner* surface of the periosteum a thin layer of osseous tissue is deposited, and the osteoblasts remain surrounded by a small space that is continued along its processes. This space and its continuations are the *lacunæ* and *canaliculi.*

With the formation of periosteal bone, the various *lamellæ* are formed. The *peripheral* are deposited beneath the periosteum. The *Haversian* system and *lamellæ* are formed in the following manner. From the inner surface of the periosteal layer, projections are formed at various angles. These meet other projections, thereby enclosing a small space, the *primitive Haversian canal. Osteoclasts* gain access and make this space regular and larger. Then *osteoblasts* lay down layer upon layer of osseous material until only a small channel, the *Haversian canal*, is left. The remains of the peripheral lamellæ between the various systems go to make up the *interstitial lamellæ.*

With the formation of the peripheral lamellæ, the network of spongy bone is removed from the center by *osteoclasts.* This leads to the formation of a *marrow cavity.* As the bone increases in size, the cavity increases in proportion, by the destruction of the surrounding bone. During the prime of life, *bone formation exceeds* *cavity formation*, but in old age, the *reverse* is the case, so that the shaft becomes thinner, and the cavity larger.

Ossification of the epiphyses occurs much later. The blood vessels from the diaphysis invade the epiphysial cartilage. Ossification begins as in the diaphysis but the extremity expands by the maintenance of a layer of cartilage around the periphery. The cartilage is replaced by cancellous bone that persists. As long as the bone continues to grow the cartilage layer is main-

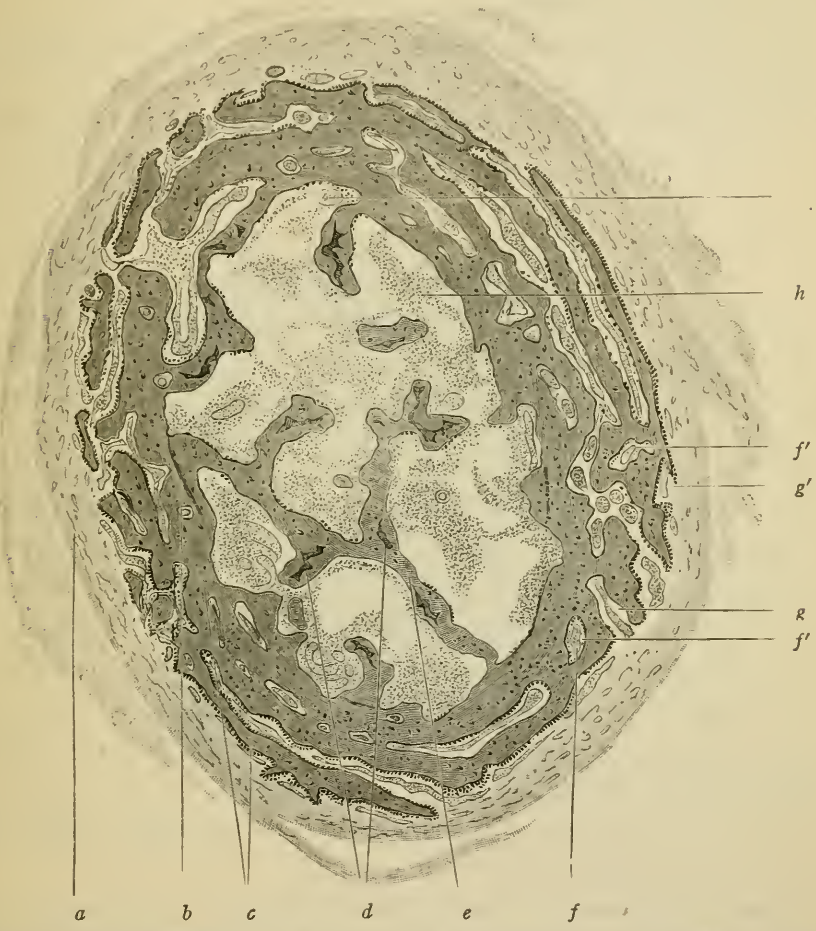

FIG. 77.—CROSS-SECTION OF A DEVELOPING BONE OF A HUMAN FETUS OF FOUR MONTHS.

a, Periosteum; *b*, boundary between endochondral and periosteal bone; *c*, perichondral bone; *d*, remains of area of calcification; *e*, endochondral bone; *f*, *f′*, blood-vessel; *g*, *g′*, developing Haversian spaces; *h*, marrow; *i*, blood-vessel (*Stöhr's Histology*.)

tained and is permanent upon the articular surface. Between each epiphysis and the diaphysis a pad of cartilage, the epiphysial cartilage, is maintained until full growth is attained. Then ossification of these discs unites these parts completely. *Apophyses* are formed in the same manner.

The bone *increases in diameter* by the continued addition of peripheral lamellæ, as a tree grows in thickness. It *grows in length* by the interposition of a disc of cartilage between the shaft and heads of the bone. The perichondrium of this disc is thicker than the periosteum of diaphysis and epiphysis producing thus a groove about the bone at the site of the disc. This is the *ossification groove* In this disc, new cartilage is formed by its perichondrium as rapidly as ossification occurs. This is the *cambium layer*, and should it ossify, that end of the bone would no longer increase in length. This change occurs normally when full height is reached.

In man, between the first and fifth years, the long bones grow chiefly in length. The rate of growth of the ends of a bone is not the same, some growing more rapidly at the proximal extremity and others at the distal extremity. As the bone increases in length and thickness absorption is also taking place as pointed out above. This is carried on by the osteoclasts. When these appear and apply themselves to the bone the surface with which they are in contact seems to melt away and a lacuna is formed. As this process continues the bone gradually disappears. This solvent action is probaby due to a secretion from the osteoclast.

This method of bone formation occurs in all bones except those of the face and of the vault of the cranium.

Intramembranous bone formation is the process whereby osseous tissue is formed within white fibrous tissue without the intervention of cartilage. At the center of ossification the mesodermal cells become enlarged, increased in number and form a sort of a membrane from which fibers radiate in all directions. These are delicate collagenous fibrils called, by Sharpey, *osteogenetic fibers*. Upon these calcareous material and later osseous tissue are deposited by the enclosed mesenchymal cells that have become osteoblasts. In this way the bony spicules of the developing structure are formed. The osteogenetic fibers spread in all directions and almost as rapidly are covered and replaced by calcareous material and osseous tissues. As these spicules anastomose freely with one another spongy bone is produced. Some of the cells form an inner and an outer layer constituting the periosteum (*i.e.*, skull bones); other cells become much enlarged and secrete osseous tissue and are the osteoblasts. The periosteums now form periosteal lamellæ as in the shafts of long bones. As the bone increases in thickness the periosteal lamellæ in the center are removed and replaced by the spongy bone or are converted into this by the action of the osteoclasts.

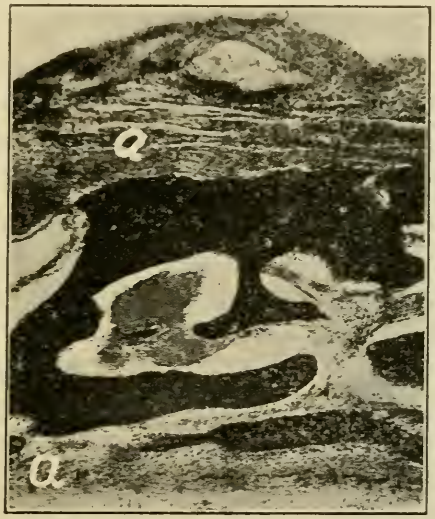

FIG. 78.—SECTION OF THE PARIETAL BONE OF A FETUS. Development of intramembranous bone. *a*, *a*, external and internal layers of the periosteum. (Photograph. Obj. 16 mm., oc. 5 ×.)

As the bone becomes vascularized the mesenchymal tissue enclosed within the bony meshes constitutes the *primitive marrow*. This consists of marrow cells, osteoblasts and a great number of osteoclasts. By the action of the latter, assisted by the osteoblasts, the internal portion of the bone is being constantly altered during the growth period. Upon the bony spicules the mesenchyme forms a thin membrane upon which is seen a layer or two of osteoblasts. This is the primitive endosteum.

Such bones increase, in thickness, as above, and laterally by the maintenance of a layer of fibrous tissue at their edges. This is the *cambium layer* that corresponds to the epiphyseal disc of long bones, and when full growth is attained, this layer ossifies, and union occurs between the various bones.

Bone readily *regenerates*, providing the periosteum is present. In fractures the fragments are united by an excess of osseous tissue called *callus*. This may be preceded by the formation of cartilage in this area. Later the osteoclasts model the sharper portions by absorption. If the periosteum be removed the part of the bone beneath this area dies. If a part of the bone beneath the periosteum be removed and the periosteum be permitted to remain, bone will be formed beneath it. In the young osteoblasts of the marrow are active in the formation of callus.

10. **Dentin** will be considered under the **teeth.**

11. **Blood** is the *only liquid connective tissue.* As it is part of the **circulatory system,** it will be considered when that is described.

CHAPTER V

MUSCLE TISSUES

Muscle tissue is a special tissue that produces the various movements of the body or organs whether under the control of the will or not. It consists chiefly of cellular elements in the form of fibers of varying shapes and lengths. Intercellular substance, or cement is absent. The muscles are all derived from the mesoderm with the exception of those of the sweat glands and iris. In lower animals they may be also of ectodermal and entodermal origin. *Myoplasm*, as yet undifferentiated into muscle fibers, is contractile as shown in the developing heart. As the primitive muscle cells, or *myoblasts*, are formed contractile *myofibrils* appear in them.

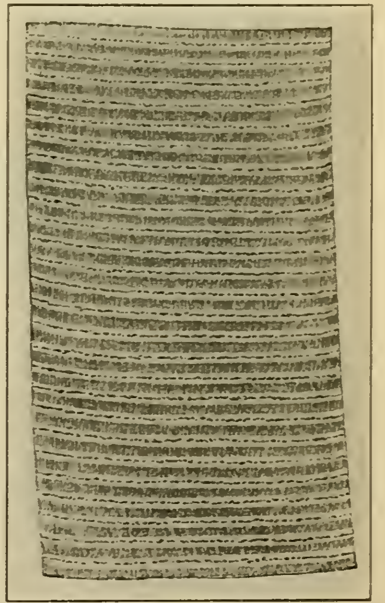

Fig. 79.—Segment of a Human Voluntary Striated Muscle Fiber Showing Dobie's Globules (Intermediate Disc) in the Light Band. (*Sharpey*.)

Muscle tissue constitutes the flesh of animals and is classified in three varieties: (1) *voluntary striated*, or *skeletal*, (2) *involuntary nonstriated*, or *smooth*, and (3) *involuntary striated*, or *cardiac*. These differ markedly in their cellular structure, arrangement, distribution and function.

Voluntary striated muscles are the most highly differentiated of the muscle tissues and are characterized by being under the control of the will. They constitute the *skeletal muscles* and even some of the visceral muscles. Their muscle cells are arranged in masses called *muscles* which are usually provided with a tendon at each end for attachment to the periosteum of the bones.

Each *fiber*, or *cell* is a long narrow cylinder and its cytoplasm constitutes a syncytium. A fiber averages about 1 inch in length though in the Sartorius muscle they may reach 5 inches. The diameter, usually 25 to 80 microms will vary in the same muscle. The largest fibers measure about 100 microns while the smallest are about 10 microns in diameter. In the male the fibers are thicker than in the female and in muscular individuals the diameter is greater (in the same muscle) than in other individuals.

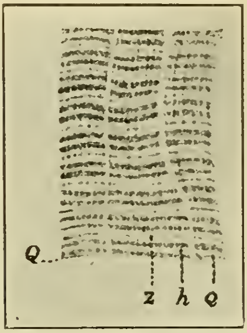

FIG. 80.

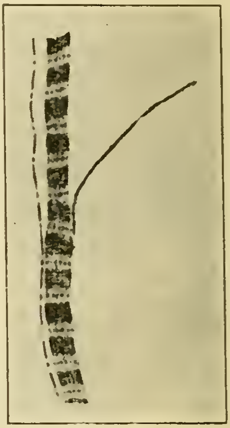

FIG. 81.

FIG. 80.—SEGMENT OF A LONGITUDINAL SECTION OF A VOLUNTARY STRIATED MUSCLE FIBER.

h, Hensen's line in the dark band Q; z, line of Dobie's globules in the light band. (*After Böhm and Davidoff.*)

FIG. 81.—SEGMENT OF A VOLUNTARY STRIATED MUSCLE FIBER OF A CRAB UNDERGOING FIBRILLATION. (*After Schäfer.*)

This same difference in thickness in different muscle is not apparent during infancy. Branched fibers are found occasionally among the muscles of the human tongue. Such fibers are numerous in the tongue of the frog.

Each fiber is composed of a large number of *fibrillæ* imbedded in a substance called *sarcoplasm*. These fibrillæ are surrounded by a delicate tubular sheath called the *sarcolemma*. This is composed of a tough, homogeneous substance that does not yield when the muscle substance ruptures. This sheath is more prominent, thicker and stronger in lower animals (fishes, amphibians) than in mammals.

The fibers show, when viewed longitudinally, light and dark bands, or lines running both transversely and longitudinally. The *longitudinal striations* are due to the alternation of the dark fibrillæ and the lighter sarcoplasm in which they are imbedded. Each fibril or *sarcostyle*, consists of a series of smaller rod-like parts. These rods, or *sarcous elements*, are separated from one another at their ends by a clear space filled with sarcoplasm and containing a small body called *Dobie's globule*. This sarcoplasm is the passive substance of the muscle fiber and contains the glycogen. Holmgren described a *trophospongium* in the sarcoplasm of voluntary striated muscle. The sarcous elements stain darkly and are doubly refractile, or *anisotropic*. The sarcoplasm stains palely, is semi-solid and is singly refractile, or *isotropic*. The sarcoplasm seems analagous to the hyaloplasm of the ordinary cells and serves as a vehicle for the chemical changes, and transference of nutrient and waste materials. The fibrillæ correspond to the spongioplasm which in the muscle cells is peculiarly arranged and has the important property of powerful contraction.

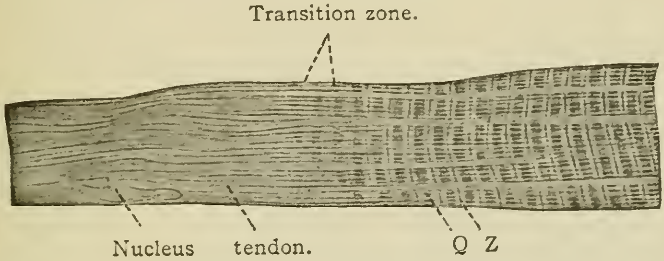

FIG. 82.—LONGITUDINAL SECTION OF A PART OF A MUSCLE FIBER FROM A HUMAN INTERNAL INTERCOSTAL MUSCLE, SHOWING ITS TRANSITION TO TENDON. ×750. (*Lewis and Stöhr.*)

The *cross-striations* consist of comparatively broad, uniform alternating *dark* and *light bands* that are usually more distinct than the longitudinal striations. The dark band is doubly refractile, or anisotropic and the light band is singly refractile, or isotropic.

Each band averages about 3 microns in breadth. The *dark band* (*Bruecker's lines*) consists of a row of sarcous elements (the rod-like parts of the sarcostyles) extending across the fiber and separated from one another by sarcoplasm, so that each dark band exhibits longitudinal striations which are continuous with those of the other bands. Not infrequently the middle of this band is marked by a clear transverse line called the *disc of Hensen*. Upon careful examination each light band is seen to be crossed at its middle by a fine and usually dotted line. This is attached peripherally to the sarcolemma and is called *Dobie's line*, or the *membrane of Krause*. The parts above and below this membrane are referred to as the *lateral discs*. All parts of the fiber embraced between two successive membranes of Krause constitute a *sarcomere*.

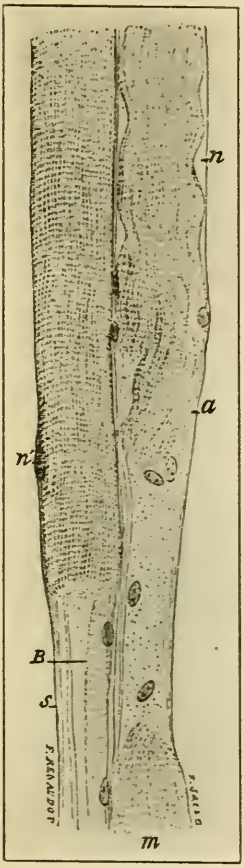

FIG. 83.—RUPTURED VOLUNTARY STRIATED MUSCLE FIBERS SHOWING THE SARCOLEMMA. *a*, End of broken fiber; *m*, muscle fiber; *n*, nucleus; *p*, shrunken muscle substance; *s*, sarcolemma. (*Jordan and Ferguson, after Ranvier.*)

The *nuclei* of a voluntary muscle fiber are very numerous (100 to 200). Each is somewhat oval in shape and contains a network of chromatin and one or two nucleoli. In mammals the nuclei lie just beneath the sarcolemma at the periphery of the sarcous substance. In the frog they are imbedded in the muscle substance. The nuclei are more numerous at the tendinous ends of the muscle than in the middle.

The *sarcolemma* is a delicate fibrous sheath that lies close to the fiber substance. It is transparent, homogeneous and tougher and thicker in lower vertebrates. It is not seen as a rule except in special preparations. If fresh muscle tissue be treated with water, the muscle substance ruptures, and the delicate membrane is shown spanning the interval.

Upon transverse section a muscle fiber is seen to be limited by the sarcolemmal sheath; beneath this are seen the nuclei located at the periphery of the muscle substance. The fibrillæ are seen to be arranged in the form of small polygonal areas called *Cohnheim's fields*. These are separated from one another by a network of sarcoplasm. This network of sarcoplasm is made very prominent by treating the muscle tissue with acid and gold chlorid after the method of Cohnheim.

There are two kinds of muscle fibers, *red* and *white*. The *white* fibers predominate in man and are poor in sarcoplasm and respond energetically when stimulated. The *red* fibers are rich in sarcoplasm, are usually thinner and respond more slowly to stimulation. These fibers also possess more nuclei that may even be imbedded in the fiber. In the rabbit these red fibers form entire muscles, while in man they are scattered among the white fibers in the Trapezius muscle.

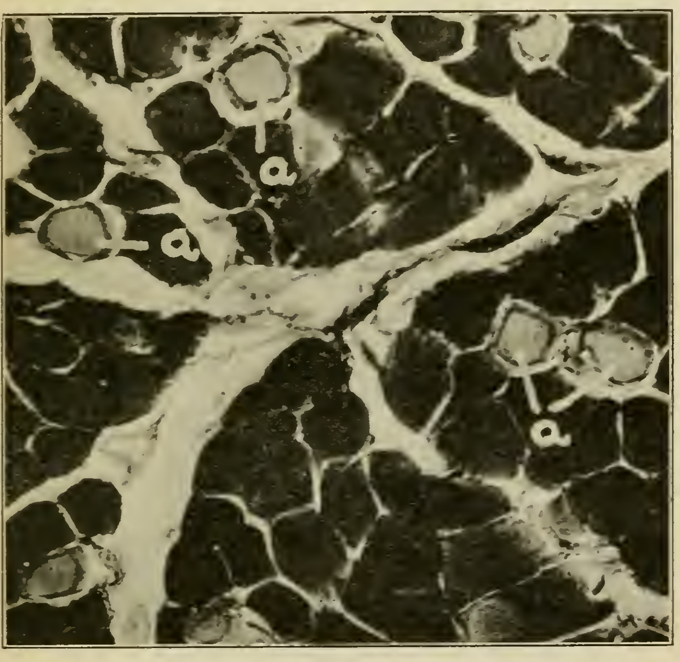

FIG. 84.—SECTION OF HUMAN VOLUNTARY STRIATED MUSCLE SHOWING SOME RED MUSCLE FIBERS.

a. a. a, Red fibers rich in sarcoplasm. (Photograph. Obj. 16 mm., oc. 7.5 X.)

During **contraction** the muscle as a whole becomes shorter and thicker. The changes in appearance of the fiber during contraction have been studied by a number of observers. Merkel believed that the muscle substance diffused itself over the entire muscle compartment at first and then accumulated at the membrane of Krause while the sarcoplasm passed to Hensen's discs, the substances, thus, becoming reversed. According to Englemann when contraction begins the membranes of Krause approach one another and the parts of each disc become indistinct, the striations are lost and the discs appear homogeneous. As the contraction progresses the striations reappear and the light disc becomes a dark band compared to the clearer disc of sarcous substance. In reality there has been no change of position of the discs, as Merkel believed, but a change in refrangibility accompanied by a decrease in volume of the dark disc at the expense of the sarcoplasm. McDougal advanced the theory that the shortening of the sarcomeres in contraction was due to the absorption of water causing the sarcomeres to swell, especially in the region of the dark discs. He later stated that he believed the absorption was due to the formation of lactic acid within or outside of the sarcomere. The contraction must be due to the movement within the sarcomere, that is from the membrane of Krause to the sarcous elements. Englemann later believed this movement to be due to *heat* developed during contraction Another view is the electrical change occurring at the adjacent surfaces of the light and

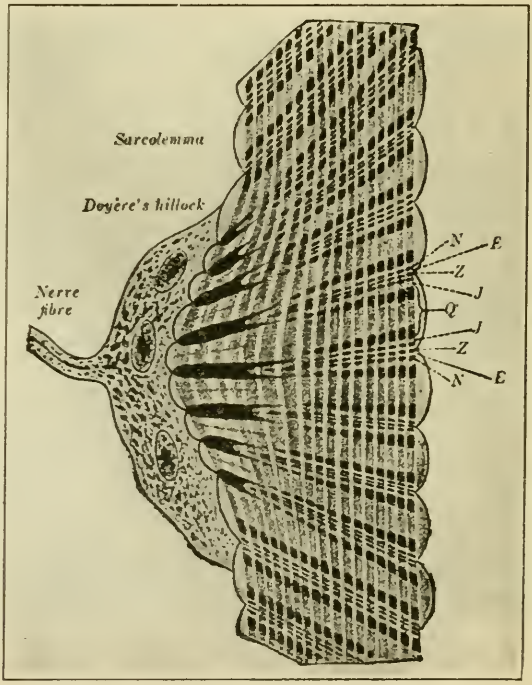

FIG. 85.—MUSCLE SHOWING LATERAL CONTRACTION WAVE. (*After Rollet.*)

dark portions of the fibers producing a change of surface tension at these points. MacDonald believes that the changes in the muscle are due to the alteration in relation of the protein molecules and the electrolytes. He believes that the onset of the contraction is marked by the new appearance of potassium salts in the central portion of each sarcomere producing, thus, a difference in osmotic pressure.

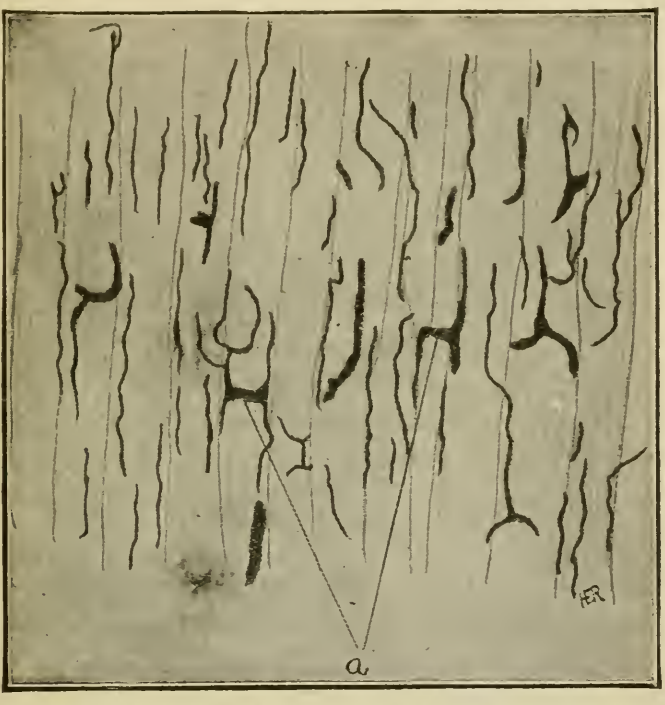

FIG. 86.—LONGITUDINAL SECTION OF VOLUNTARY MUSCLE OF A GUINEA-PIG, INJECTED, SHOWING THE COURSE OF THE CAPILLARIES. *a*, Ampullæ. (*Radasch, Reference Handbook of the Medical Sciences.*)

A **muscle** consists of a definite collection of muscle fibers. The entire muscle is enclosed in a thin sheath of white fibrous tissue called the *epimysium*; this sends in septa that divide the muscle into large *secondary bundles*, or *fasciculi*. The secondary bundles are composed of a number of *primary fasciculi*, each of which is surrounded by a sheath called the *perimysium*. From the perimysium fibers extend into the bundles running between the individual muscle fibers, forming a network and supporting the capillary blood-vessels, lymphatics and nerves. This network is the *endomysium*. When the muscle fibers form the tendon, the muscle cells end abruptly and the nuclei are more numerous here. The tendon bundles begin abruptly and continue parallel to one another while the areolar tissues of the muscle and tendon are continuous.

Muscles are very vascular. The larger vessels pierce the epimysium and send branches along the septa between the primary bundles; these vessels run parallel to the long axis of the muscle. Branches enter the primary fasciculi and form capillaries, that run parallel to the long axis of the muscle, forming a long meshwork between the fibers. At intervals transverse connections between the longitudinal capillaries are seen and these are the *ampullæ* that serve to take the tension off of the capillaries during muscle contraction. As a rule the smaller the fibers the more abundant the vessels and the closer the capillary meshwork.

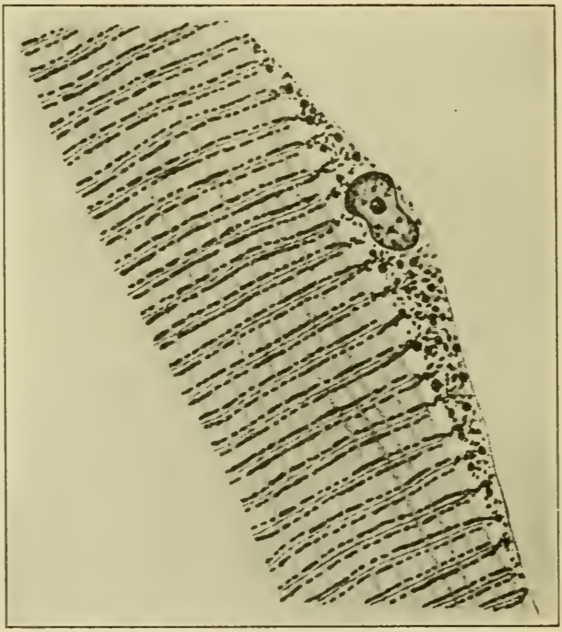

Fig. 87.—Trophocyte in Relation with a Muscle Fiber of the Human Tongue. The nutritive granules are being "fed" into the dark discs. (*Nanna Svartz*, Anat, Anz., March, 1914.)

The *nourishment of muscle fibers* is not carried on in the usual way. Holmgren and Thulin, in their study of the tissue of insects, found special cells, *trophocytes*, present; these took from the blood and lymph the various nutritive elements and, after modifying them, transferred the products to the tissue cells. These trophocytes are necessary to the specialized tissues (muscle and nerve). The relation of trophocytes and muscle cells has more recently been studied by Nana Svartz, in the human tongue. The trophocytes are large, granular elements that clasp the muscle cells. The granules are apparently nutritive in function resembling the tigroid bodies of the nerve cells. They are arranged in rows and are passed into the muscle cells and during the contraction of the muscle fiber the granules dissolve. The trophocytes exhibit peculiar and characteristic changes in appearance, number and arrangement of granules and the nucleus during the contraction wave of the fiber. This seems to indicate that they are not indifferent cells. The direct passage of substances from the trophoctyes to the muscle cells is demonstrable.

Lymphatic vessels are said to be absent in voluntary muscles. The lymph spaces between the muscle fibers empty the lymph into the muscle sheaths and tendon.

The **nerves** are large and enter with the vessels. They pass between the fasciculi and anastomose with one another. After piercing the epimysium the nerve follows the septa to the primary fasciculi and separates into small groups of fibers. As such a nerve does not contain as many fibers as there are muscle cells each nerve fiber will give off a number of collaterals or branches so that ultimately there will be a nerve fiber for each muscle fiber, and one primary nerve fiber will supply a number of muscle fibers. As the terminal nerve fiber pierces the sarcolemmal sheath the neurilemma and myelin sheath blend with the sarcolemma and the naked axis cylinder alone enters the muscle substance. This passes to the *sole-plate* which is a granular mass of nucleated protoplasm containing several nuclei. Within this the fibrillæ of the nerve fiber terminate in bulbous enlargements, which,with the sole-plate constitute the *end-plate*. There is but one organ to each muscle fiber.

INVOLUNTARY NONSTRIATED MUSCLE

The **involuntary nonstriated,** or **smooth muscle tissue** is less abundant than the preceding type and is not so highly differ-

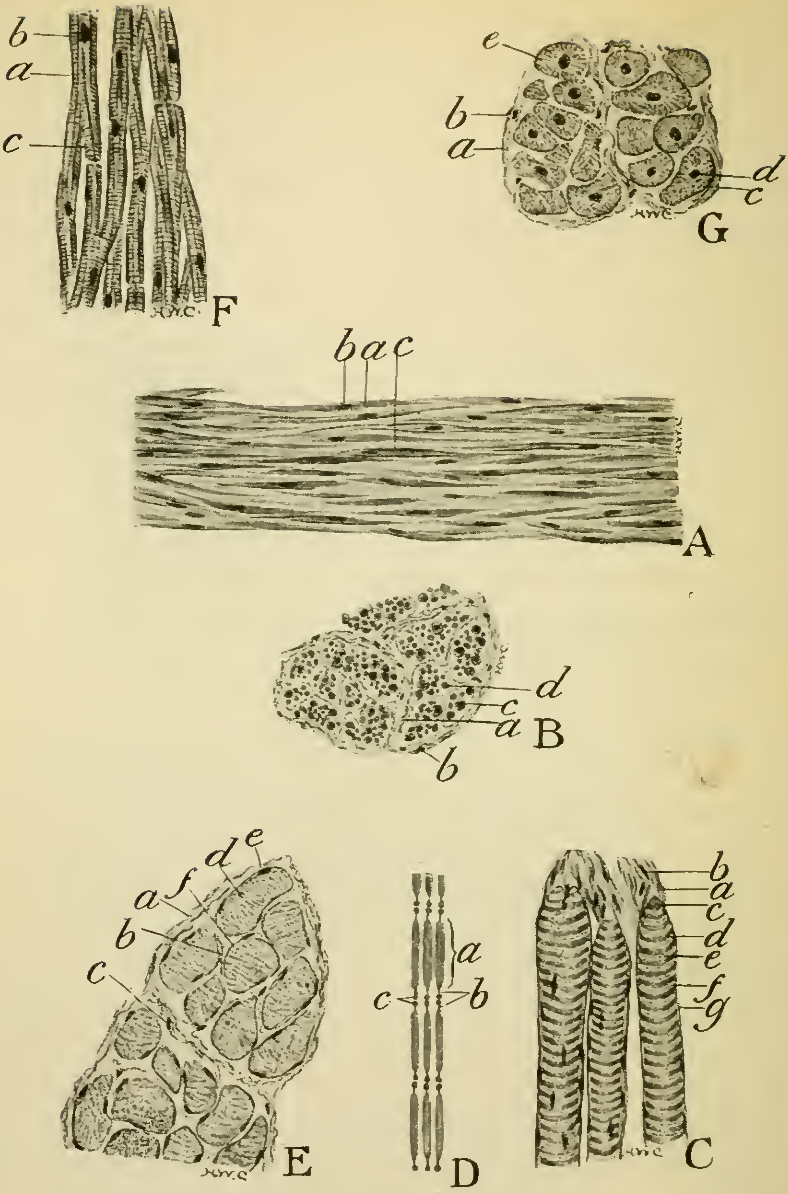

Fig. 88.

A.—Longitudinal section of smooth muscle fibers: *a*, muscle fiber; *b*, nucleus; *c*, fibrous tissue between fibers. B.—Cross-section of smooth muscle fibers: *a*, perimysial connective tissue; *b*, blood-vessel; *c*, nucleated fiber; *d*, nonnucleated fiber. C.—Longitudinal section of voluntary muscle fibers: *a*, sarcolemma; *b*, nucleus; *c*, end of muscle fiber; *d*, dark bands; *e*, intermediate disc; *f*, nucleus; *g*, lateral disc. D.—Diagrammatic section of cross and long striations: *a*, dark disc; *b*, lateral discs; *c*, intermediate disc. E.—Cross-section of voluntary muscle: *a*, perimysium; *b*, endoentiated. In most organs the fibers are arranged into distinct layers and not in the form of muscles. They form the muscle coats of hollow and tube-like organs. The fibers are said to be united to one another by a small amount of intercellular cement that can be brought out by the silver nitrate method of staining. When spaces between the fibers occur, delicate intercellular bridges are seen connecting the cells in the form of a syncytium. These bridges are the continuation of the peripheral fibrillar cytoplasm of the cells.

Each *fiber*, or *cell* is a small, spindle-shaped element measuring from 40 to 200 microns in length and 3 to 8 microns in thickness. Larger fibers are seen in the pregnant uterus where the length is often 500 to 600 microns and the thickness also increased in proportion. In the aorta and some of the larger blood-vessels these muscle cells are very irregular in shape. The ends of the fibers may be branched or forked as in the aorta and bladder.

The *sarcous substance* may show longitudinal striations (but no transverse) due to the presence of coarser *peripheral* fibrillæ and *deeper* and more delicate fibrils. These are doubly refractile and are separated by varying amounts of sarcoplasm. In the developing fibers the fibrils arise from small granules that are apparently derived from the mitochondria and are called *myochondria*. The peripheral, or border fibrils are coarser and are the ones that form the intercellular bridges; they serve to connect the cells into a syncytium. The deeper are the more delicate and seem to be the ones most concerned in the contraction of the cells. The *sarcoplasm* may contain granules at the poles of the nuclei and immediately surrounding the nucleus is of an undifferentiated character. This contains glycogen granules, lipoids and mitochondria.

The *nucleus* is usually long and rod-shaped and located in the center of the cell. It contains a distinct chromatin network and one or two nucleoli. During contraction of the cell the nucleus

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mysium; *c*, nucleus of perimysium; *d*, fibrillæ; *e*, nucleus of muscle; *f*, sarcolemma. F.—Longitudinal section of cardiac muscle fibers: *a*, muscle fiber; *b*, nucleus; *c*, branch. G.—Cross-section of cardiac muscle fibers: *a*, perimysial sheath; *b*, nucleus of sheath; *c*, muscle fiber; *d*, nucleus; *e*, radial plates of fibrillæ.

becomes shorter and thicker (or even a short spiral) and the chromatin seems to be forced towards its poles. A centriole is present at the side of the nucleus.

Although a sarcolemma is not present each cell is surrounded by a delicate membrane which may be a layer of peripheral, homogeneous cytoplasm. In contracted fibers this membrane may be wrinkled giving the appearance of indistinct transverse striations.

The smooth muscle fibers are collected into fasciculi of varying sizes that are usually arranged parallel to one another forming layers. In some organs, however, these fasciculi interlace, as in the uterus, vagina and bladder.

This type of muscle is found in the hollow viscera as the lower part of the esophagus, the stomach and intestines, the trachea and bronchial tubes, the ureter, bladder, urethra, penis, the ovaries, oviducts, uterus and vagina, the ducts of glands, the skin, the blood-vessels, lymph vessels, the eyeball and in the capsules of certain organs as the spleen, lymph nodes and prostate.

The *blood-vessels* are less numerous than in the voluntary striated variety. The capillaries form plexuses around the fibers.

Some organs, as the stomach and intestines, have abundant lymphatic plexuses between the layers. Other organs are not so well supplied.

The *nerves* are from the sympathetic system. In the stomach and intestines these amyelinated nerves form a prominent plexus between the layers of the muscle coat and another in the submucous coat. From these plexuses the terminal fibers pass to the muscle fibers. In other organs there may be more delicate plexuses or simply small ganglia in relation with the organs and from these the terminal fibers pass to the muscle fibers. Here the nerve fibers end as tapered or bulbous extremities that are applied to the surface of the muscle cells.

INVOLUNTARY STRIATED OR CARDIAC MUSCLE

The **cardiac muscle** resembles both of the preceding in its characteristics. The fibers are cylindric in form and have both transverse and longitudinal striation, as in the voluntary type. Each possesses usually a single nucleus, which is centrally placed, and no sarcolemma, the fibers are arranged in layers and are not under control of the will and in these they resemble the smooth type.

The *cardiac muscle fibers* are usually described as short stubby cylinders that measure 100 to 200 microns in length and 25 to 40 microns in thickness. These branch and anastomose freely so that there is a continuity of the fibers through both sets of chambers of the heart. As a result of this anastomosis and the continuity of fibrils from one so-called cell to another, heart muscle constitutes a syncytium. The cell boundaries are not clear, but for the sake of description the term cell or fiber will be used. Some observers maintain that septa do occur, indicating transverse segmentation, but the fibrils are seen passing through these septa continuing from one cell to the other.

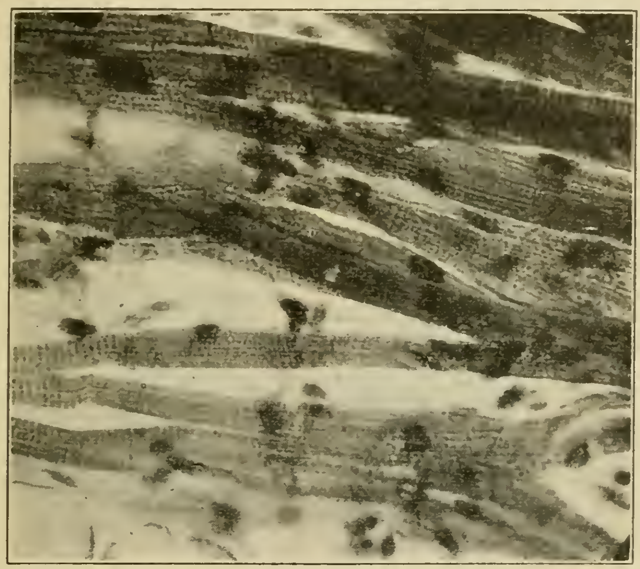


Fig. 89.—Section of Human Cardiac Muscle Showing Striations and Branches. (Photograph. Obj. 4 mm., oc. 7.5 ×.)

The *longitudinal striations* are due to the presence of fibrillæ or sarcostyles, imbedded in the sarcoplasm. Although there is no distinction between deep and border fibrils as in the smooth type, still the fibrils are specially arranged in rows that radiate from the central area. They are anisotropic. These fibrils are not continuous but interrupted at regular intervals so that as in voluntary striated muscle there is an alternation of light and dark bands producing the *transverse striations.* The light bands are chiefly sarcoplasm containing the mitochondria, glycogen, liposomes, lipoid and albuminoid granules. This band is divided into the intermediate (Dobie's membrane) and the two lateral discs. The dark band (Bruecker's) is crossed by the *line of Hensen.*

There is usually a single, large, oval and centrally placed *nucleus,* though two may at times be seen in one cell. The chrómatin network is distinct and each nucleus is usually surrounded by an area of undifferentiated cytoplasm containing granules and fat droplets. A delicate limiting cell membrane is present and some call it a sarcolemma.

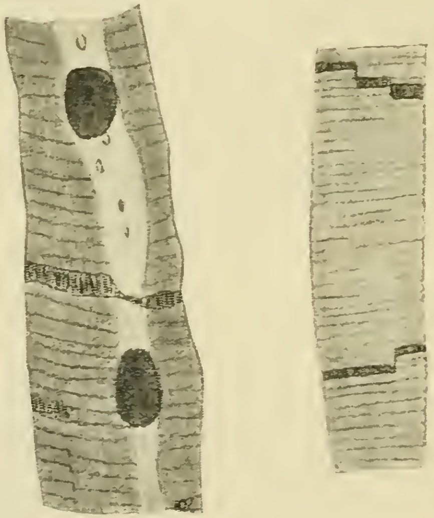


Fig. 90.—Muscle Tissue from the Adult Heart Showing the Intersegmental Septa and the Nuclei Lying in the Undifferentiated Sarcoplasm. (*After Palczewska.*)

The muscle fibers of the atrioventricular bundle correspond to the Purkinjé fibers of the hearts of lower animals. The muscle fibers, less differentiated than those of the myocardium, are striated but the sarcoplasm predominates. The fibrillæ are few and peripherally placed forming a circle, or groups that are irregular or triangular. The volume and size of each fiber are greater than in the ordinary cardiac fibers. They are less branched and the intercallated discs are fewer in number. The cytoplasm is rich in glycogen and pigment granules may be present. Cell boundaries cannot be definitely located so that this tissue is a syncytium. This bundle is distinctly separated from the heart muscle and seems to appear early in development. It has to do with the conduction of the contraction wave.

According to some investigators the heart muscle represents a syncytium in which no distinct cell boundaries are to be detected. Others maintain that their individual cells as above described are shown by special stain methods. After treatment with special reagents, the muscle syncytium seems to be separated at fairly regular intervals by the *intercallated discs;* these may be straight bands, step-like or serrated. These are irregular as to form and position. These may extend across the fiber or only a short distance. They may be arranged annularly or in spiral form. They are merely peripheral in position never extending all of the way through a fiber or even in to the axial core of sarcoplasm. They are permanent structures and are composed of units corresponding to portions of a single fibril that may be granular or compact. They appear late in fetal life. Some believe them to be due to a "fixed phase of contraction wave" or due to an irresistible strain condition. The fibrillæ continue through the discs from one so-called cell to another.

The **blood-vessels** are very numerous in the heart. The capillaries lie in close relation with the muscle substance and may even lie in grooves on the fibers. In some animals the capillaries are seen imbedded in the muscle substance.

The **lymphatics** are very numerous and follow the course of the blood-vessels. The lymph capillaries form a network throughout the intermuscular tissue forming vessels that pass toward the serous surfaces and ultimately toward the base of the heart.

Cardiac muscle is supplied by the *sympathetic nerve system.* These fibers may form delicate plexuses at the intersections of which are found ganglia of various sizes. Individual amyelinated fibers extend to each muscle cell and terminate upon its surface in one or more granules or bulbs. According to Huber and others the nerve fibers terminate in many fine fibrils that spread over each nucleated segment or cell.

Muscle tissues are derived from special portions of the mesoderm called myotomes, or muscle plates. The cells that form the muscle fibers are the *myoblasts* and they multiply very rapidly. In the formation of the voluntary striated muscles, the myoblasts elongate and increase in number. The myoblasts become separated from the mesenchymal cells, the latter forming the fascia and tendons. The protoplasm contains granules that are the mitochondria, according to Meves and Duesburg. The fibrils develop independently of one another. During the second month, in the human embryo, the granules form peripheral longitudinal striæ (the future muscle substance) and a delicate membrane appears derived probably from the mesenchyme. The nucleus lies in the central, undifferentiated cytoplasm. More striæ are formed and by the regular interruption of the fibrillæ the cross striations appear. By the sixth month of fetal life there remains but a small central core of undifferentiated cytoplasm containing the nucleus. Later the nuclei multiply and assume a peripheral location. In the trout embryo the first fibril, by a radial longitudinal splitting, forms a peripheral ring of fibrils and the central fibrils are formed by a splitting of those of the peripheral ring. As the central area becomes invaded by the fibrils the nuclei migrate to the periphery or occupy the deeper portion according to the cell. The remaining undifferentiated cytoplasm between the fibrils constitutes the sarcoplasm. Thus the white fibers are formed. In the red fibers fewer fibrils are formed and the sarcoplasm predominates. This variety represents an intermediate form between the myoblasts and the white variety.

Most of the smooth muscles are derived from the myoblasts of the mesoderm; the exceptions are the muscles of the sweat glands and the iris, which are of epithelial origin. In either case the cells elongate and become spindle-shaped while the nucleus elongates. The cytoplasm gradually shows the formation of fibrils that soon completely occupy the cytoplasm. These fibrils become differentiated into central finer and peripheral coarser ones; the latter are supposed to arise by the fusion of the finer ones and continue from one cell to another. These fibrils are continuous and uninterrupted so that transverse striations do not appear.

The early stages of the cardiac muscle are similar to the above. Later, however, the cells seem to join to form a syncytium.

After becoming completely developed voluntary striated fibers continue to increase in size to birth and from that time to adult life. They double their size in the last half of gestation and in the adult are about five times the size as at birth. The increase in the number of muscle cells is due to the presence of myoblasts in the muscles, even in the adult.

Although formerly it was believed that muscle tissue did not regenerate, it appears that diseased or cut areas are later joined by muscle tissue. Some consider this due to the presence of myoblasts but Schmincke states that the existing fibers bud at the ends. Pfitzner found that in artificially produced lesions of smooth muscle tissue regeneration occurs by the neighboring cells multiplying by karyokinesis.

The accompanying table gives a résumé of the general characteristics of the various types of muscle tissue.

Characteristic	Voluntary striated	Smooth	Cardiac
Shape.	Long cylinder.	Spindle.	Stubby cylinder. (?)
Length.	1–5 inches.	25–500 microns.	100–200 microns.
Nucleus.			
Number.	Many.	One.	One.
Location.	Peripheral.	Central.	Central.
Shape.	Intermediate.	Rod.	Oval.
Striations.	Cross and long.	(Longitudinal)	Cross and long.
Sarcolemma.	Present.	None.	None.
Branches.	Occasional.	(Occasional.)	Always.
Arrangement.	In masses called muscles.	In layers.	As a syncytium.
Control.	By will.	Not by will.	Not by will.

CHAPTER VI

NERVE TISSUES

The **nerve tissues** are the most highly differentiated of all of the tissues. By means of these the various organs and structures are connected and associated so that they can work together and accomplish some definite object. By means of the nerve system the individual is made cognizant of his environments through his sense organs. Nerve tissues consist of cells and intercellular substance like the other varieties of tissues and, as in connective tissues, the intercellular substance predominates.

There are **two varieties, gray** and **white.** The **gray** is characterized by a grayish color: in the cerebrum and cerebellum it is divided into layers while in the spinal cord, brain stem, and ganglia the arrangements is somewhat different. It consists of *cells* and their *processes, myelinated* and *amyelinated nerve fibers* and *neuroglia,* the special supportive substance of the nerve system. The *white nerve tissue* of the central nerve system consists chiefly of myelinated nerve fibers and neuroglia and a small amount of white fibrous connective tissue. The **peripheral nerve system** consists of nerve fibers supported mainly by white fibrous connective tissue, and some ganglia.

The nerve system consists of a series interrelated and interconnected units that give a continuity of impulse from the central system to the periphery and *vice versa.* These units are called the **neurons;** each neuron consists of the nerve cell and its various processes. The nerve cell comprises the *cytom,* or cell body, the immediate dendritic processes and the proximal portion of the axone. The distal portion of the axone and the distal portion of the main dendrite, if it leaves the gray substance and becomes a nerve fiber as in the sensor system, constitute the *nerve fibers.* These fibers may be but a few millimeters in length or several feet, as evidenced by those nerves of the extremities.

Nerve cells are found only in gray nerve tissue. A **typic nerve cell** consists of a cell body, from which a number of processes extend, a nucleus, nucleolus and centrosome. The whole structure comprises the **neuron,** or **neurocyte.**

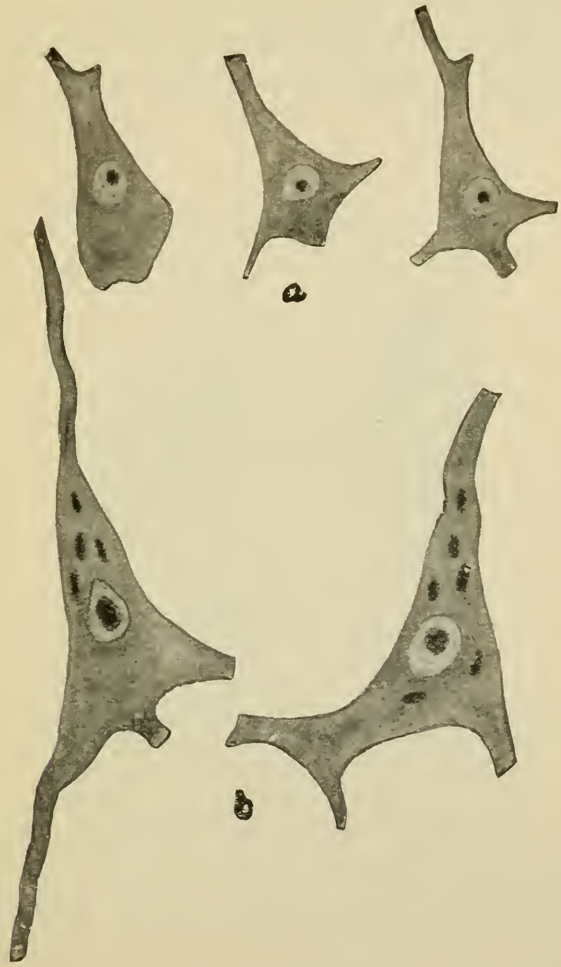


FIG. 91.—TYPIC NERVE CELLS.
a. From a human spinal cord; *b.* from the motor area of the human brain showing tigroid bodies. Drawn from slides. (*Radasch, Reference Handbook of the Medical Sciences.*)

The *cell-body,* or *cytom* is composed of a granular and fibrillar cytoplasm; the latter at the point of origin of the main process forms the *axis cylinder hillock.* The fibrillar network is of two kinds. A fine meshwork, seemingly containing myelin, was found by Gólgi.

It stains darkly after prolonged exposure to osmic acid and is unconnected with the neurofibrils. The others are the *neurofibrils* that can be seen only after careful preparation after Golgi's method and must be examined under a high-power objective.

Neurofibrils, first described by Max Schultze, are seen passing into and through nerve cells without forming junctions with one another and extend also into all of the processes. These fibrils are of a semi-solid nature, apparently, as they easily become varicose in form; they vary, apparently, with functional activity. Cajal and Tello have found that in the hibernating lizard, during winter sleep, these fibrils are less numerous and thicker than in the active animals. These fibers pass from one cell to another and terminate there. These fibrils respond readily to the intravitam methylene blue and silver nitrate stains.

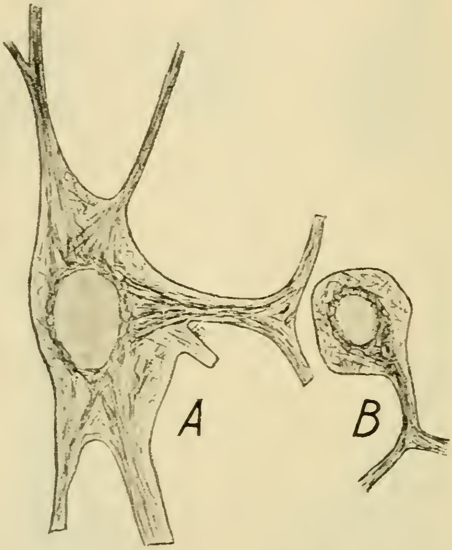


Fig. 92.—Nerve Cells Showing Neurofibrils.
A, From the anterior corpora quadrigemina of a kitten. B, From a spinal ganglion of an embryo. (*After Cajal.*)

In the meshes of the fibrils are seen the granules and a homogeneous substance that stains but faintly. The latter is comparable to the hyaloplasm of the typic cell. The granules are of two kinds, *oxyphilic* and *basophilic*. The *oxyphilic granules* are the more numerous and the smaller and are seen only after special stains have been employed. The *basophilic granules*, or *corpuscles of Nissl*, are large but inconstant.

The *corpuscles of Nissl*, or *tigroid bodies* consist of nucleoprotein containing organically combined iron, as pointed out by MacCallum. The tigroid nuclein is soluble in weak solutions of soda. They are usually large, flake-like bodies that respond readily to methylene blue, thionin, or toluidin blue stains. They are derived from the nucleus appearing first in the form of chromidia. The presence and position of these bodies depends upon the functional activity of the cell; they may be scattered or arranged in two groups, one near the nucleus and one near the periphery of the cell; they may be arranged concentrically around a well defined centrosome. In fatigued cells they disintegrate and disappear although Dollay has shown that if the activity is not excessive they first increase in amount. These changes are called *chromatolysis*, or *Nissl's degeneration*. Similar changes occur in these granules, if the axones of the cells be cut,

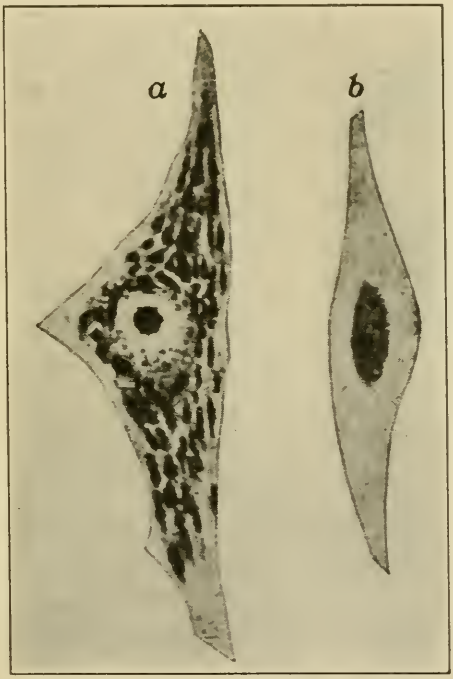


Fig. 93.—Motor Nerve Cells from the Brain of a Dog.
a. Normal resting cell; *b*. fatigued cell. (*Schäfer after Mann.*)

twenty-four to forty-eight hours after section and being completed in fifteen to twenty-four days. Various poisons including toxins produce a like effect. With removal of the cause regeneration usually takes place. In disease, or section of the axone regeneration does not take place. Crile believes that Nissl's substance is volatile and unstable and depends upon adrenalin for its existence. The tyroid bodies are seemingly nutritive in function.

In certain portions of the nerve system *other granules*, usually brownish-yellow, or black, are found in the cytoplasm. This is the *substantia nigra* of the locus cœruleus. This pigment contains lecithin and tends to increase with age, making its appearance at about the third year. It is more common in man than in the lower animals.

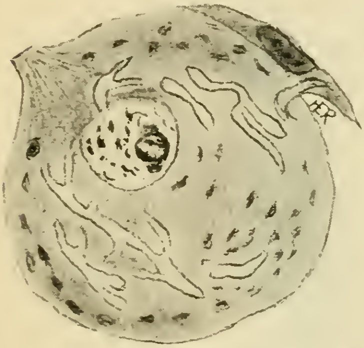


Fig. 94.—Trophospongium within a Ganglion Cell. (*After Holmgren.*)

Schirkogoroff studied the *mitochondria* in the nerve cells of the rabbit and found them more or less abundant. They were best developed in the cells of the spinal cord, oblongata and Purkinje cells of the cerebellum, in the small cells of the basal ganglia of the brain they were small and few in number. Their presence in the axones is doubtful though some state that they are found in all of the cell processes. They have also been found in the spinal ganglion cells of man and are probably concerned with the metabolism of the cell.

Holmgren has found a fine network of *juice canals*, or *trophospongium*, in the cytoplasm of many of the nerve cells, especially those of the ganglia. He believes that these canals may undergo constant changes.

Golgi and others have described a reticular investment covering the nerve cell and extending for a variable distance upon the processes. Its nature and function are unknown. Some believe that it represents an interlacement of the terminal ramifications of the axones of other cells; others believe that it is of neuroglial origin. Around nerve cells, especially of the ganglia, there is a well defined lymph space that is lined with endothelial cells.

The *nucleus* is usually large, pale and eccentrically placed. The nuclear membrane is distinct and stains deeply. The chromatin is scant, the karyosomes few and small and usually attached to the inner surface of the nuclear membrane. At times chromatophilic granules are found in the nucleoplasm.

The *nucleolus* is usually very large and stains deeply. It is located near the middle of the nucleus and is usually readily discernible with the low power.

Centrosomes with attraction spheres have been found in the nerve cells of some mammals.

Cell Processes.—Extending from the cytom will be found one or more processes and cells are classified according to their number as unipolar, bipolar and multipolar. The main process is called the **axone** and the other the **dendrite.**

The main process is called the **axone, axis cylinder,** or **neurit** and represents a direct continuation of the cytoplasm of the cytom. It starts at the axis cylinder hillock and consists of a cylindric collection of neurofibrils imbedded in neuroplasm and surrounded by a delicate membrane called the *axilemma.* The presence of this membrane is denied by some. The axis-cylinder hillock and the process are devoid of granules. The process is uniform in diameter, smooth in contour and may give off branches called collaterals; these are said to be more numerous near the proximal than the distal end of the axone. Near its termination the axone may bifurcate. Both axone and collaterals usually end in a brush-like mass of branchlets called *telodendria* (better *teleneurites*). At times these terminals are knobs or plates. Occasionally an axone may arise from a dendrite. The axone extends a variable distance from the cytom and its course as to whether it remains in the gray substance or leaves it gives rise to a classification of nerve cells into first and second types.

A cell of the **first type** (**Deiter's cell**) is one in which the axone leaves the gray substance to become a myelinated nerve fiber, or a sympathetic nerve fiber. A cell of the **second type** (**Golgi's cell**) is one in which the axone does not leave the gray substance. In a unipolar cell the single process soon divides into two, one the axone and the other the dendrite.

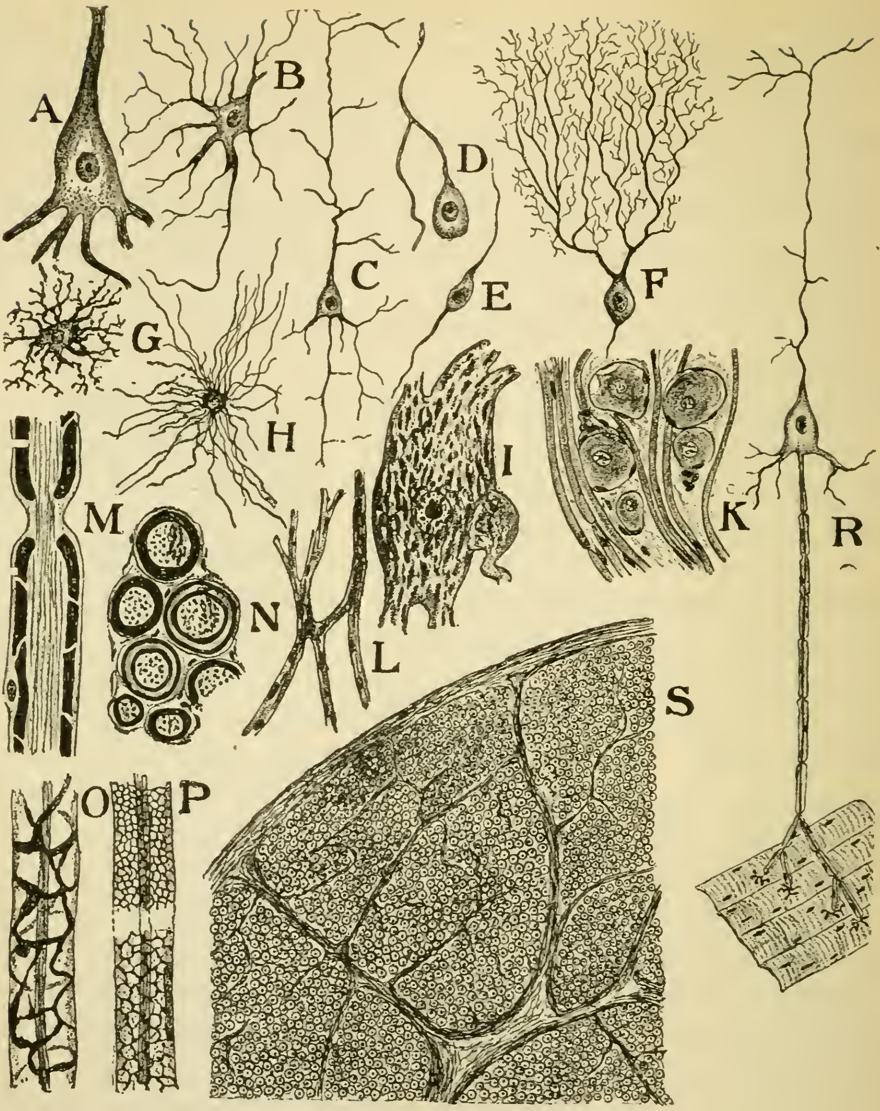


Fig. 95.

A. Multipolar cell from cerebral cortex. B. Multipolar cell from spinal cord. C. Pyramidal cell from cerebral cortex. D. Unipolar cell. E. Bipolar cell. F. Cell of Purkinje, antler cell. G. Mossy cell. H. Spider cell. I. Cell from spinal cord of an ox, showing pigment granules. K. Ganglion. L. Sympathetic or amyelinated fibers. M. Longitudinal section of myelinated nerve fiber: *a*, neurilemma; *b*, myelin sheath; *c*, axis cylinder; *d*, node of Ranvier; *e*, nucleus. N. Cross-section of osmicated nerve fibers. O. Myelinated nerve fiber of a guinea-pig showing the reticulum. P. Myelinated nerve fibers of a toad, showing reticulum (neurokeratin). R. Motor neuron, showing nerve cell, dendrites, axis cylinder and ending of latter in a muscle. S. Cross-section of nerve trunk.

The **dendrites,** or **dendrons** are secondary processes. As they arise from the cytom they are relative thick, but as they branch repeatedly they taper rapidly. These branches do not usually extend far from the cell-body and terminate in fine branches, *telodendria,* that end in relation with the telodendria, or teleneurites of neighboring cells. Occasionally the dendrite does not branch until it is quite a distance from the cytom; this is the case in the sensor cells in the various ganglia connected with the sensor nerves, where the dendrites will be several feet in length and reach the periphery before they arborize. The network produced by the various telodendrites forms a considerable portion of the gray nerve tissue. The thorny appearance of dendrites in Golgi preparations is due to the presence of minute lateral projections called *gemmules.*

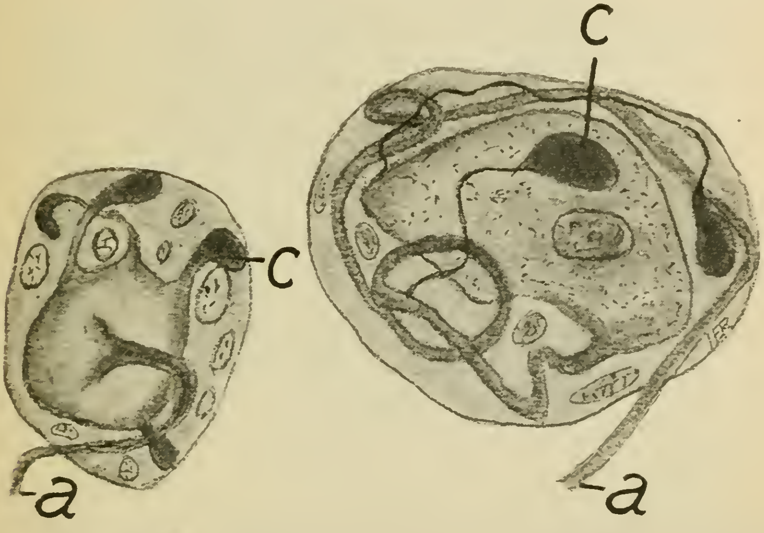


FIG. 96.—CELLS FROM CEREBROSPINAL GANGLIA SHOWING INTRACAPSULAR KNOBBED DENDRITES *c, c; a, a,* AXONES. (*After Cajal.*)

Unipolar cells possessing but one process, are found in the ganglia of the dorsal roots of the spinal nerves and in the ganglia connected with the trigeminal and vagal nerves and occasionally among the cells in the ventral horns of the spinal cord. The cells are usually spherical, or nearly so, in shape and the process close to the cytom is surrounded by a myelin sheath. At a short distance from the cell the process divides like a T or Y, one process entering the central nerve system (axone) and the other extending to the periphery (myelinated dendrite). Embryologically these are bipolar cells in which the cytom grew unequally so that gradually the two processes were thrown side by side; at the same time the cytoplasm became so extended as to form the undivided portion of the process. As a result this seemingly unipolar cell is bipolar functionally.

Bipolar cells are found in the cochlear and vestibular ganglia connected with the corresponding divisions of the auditory nerve; in the olfactory mucosa; as the rod and cone cells of the retina; as the Purkinje cells of the cerebellum. Each possesses an axone and a single dendrite.

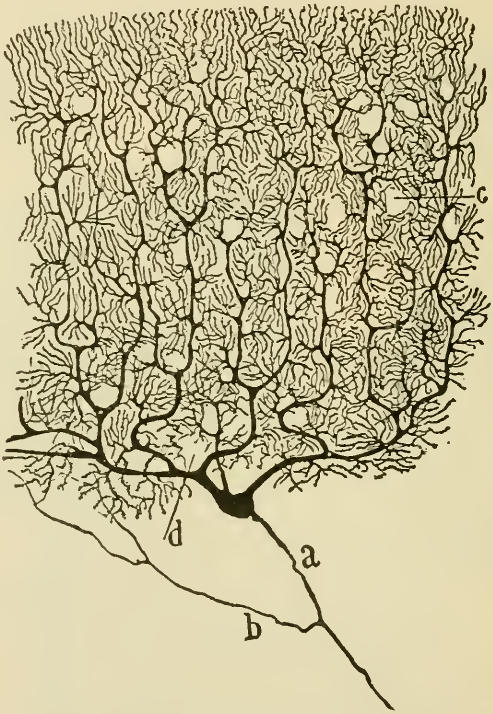


Fig. 97.—Purkinjé Cell of the Cerebellum.
a. Azone; *b,* collateral; *c, d,* dendrites and telodendrites. (*Cajal.*)

The **multipolar cells** are the most numerous and are found in the cerebral cortex and in the gray substance of the spinal cord and brain stem. These cells possess three or more processes, one axone and the remainder dendrites.

Nerve cells vary in size from 4μ to 9μ in diameter, for the smallest, to 75μ to 150μ for the largest. The *former* are the granule cells of the cerebellar cortex and the *latter* are those of the ventral horns of the spinal cord. The next largest are the large pyramidal cells of the cerebral cortex ("giant cells of Betz," motor area). Nerve cells *without an axone* are found in the retina and olfactory bulb. Neurons are unable to reproduce themselves; if the axone becomes destroyed it may regenerate but if the cytom is destroyed it is never replaced.

According to the neurone theory the nerve system consists of a series of closely related and physiologically corelated elements from the central system to the periphery; in other words one neuron does not extend from the center to the periphery. At least two and as many as six are concerned in the various pathways. These related neurons are not directly connected to one another although the processes of one cell may end around the body of, or in contact with the processes of another cell. This has been shown by special stain methods, by the study of the nerve system in certain diseases and injuries and by the study of the development of the nerve cells and fibers. The cells and processes alike are affected by degenerative processes, but the preceding or succeeding neurons are not affected.

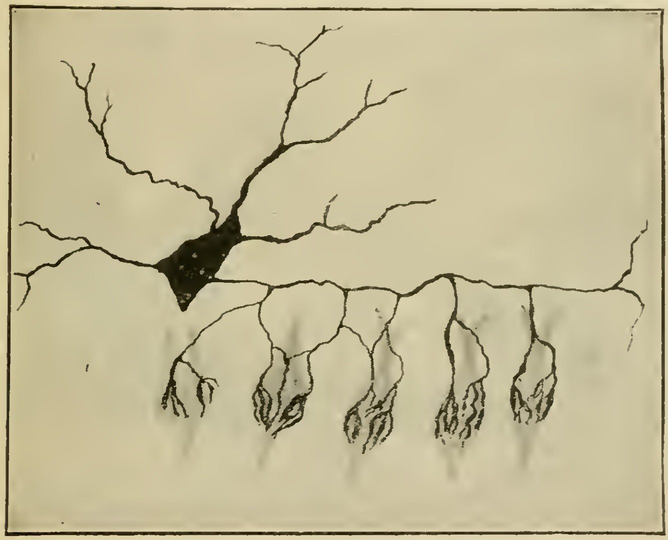


FIG. 98.—SYNAPSE OF THE INVESTMENT TYPE.
(*Radasch, Reference Handbook of the Medical Sciences.*)

The ramifications of the axone of one cell about the body of another cell or its processes constitute a *synapse.* When the teleneurites surround the cell body this form of synapse is called an *investment*; when the teleneurites come in relation with the telodendrites of another cell this constitutes an *interlacement.* Occasionally synapses may occur between the dendrites of two cells. Another peculiar form of synapse is that in which the axone does not branch at its termination but ends in a bulb-like enlargement upon the body of another cell, as in the trapezoid and ventral acoustic nuclei of the brain stem.

The **neuroglia,** or **glial substance,** is the peculiar supportive tissue of the nerve system. Like the nerve cells it is of ectodermal origin. Unlike the intercellular substance of other tissues it is not the result of the activity of the functionating (nerve) cells but the glial substance itself consists of *cells* and *intercellular substance.* The glial cells give rise to the glial fibers.

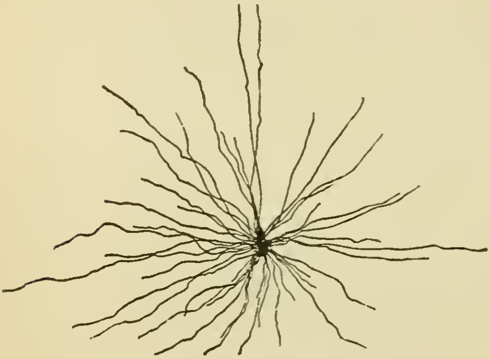


FIG. 99.—SPIDER GLIAL CELL. (*After Andriezen.*)

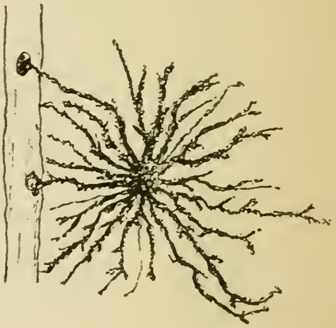


FIG. 100.—MOSSY GLIAL CELL IN RELATION WITH A CAPILLARY. (*After Andriezen.*)

Glial cells are of two kinds *ependymal cells* and *astrocytes.* The *ependymal cells* are apparently some of the original elements of the neural tube. They represent the remainder of those indifferent cells that gave origin to the neuroblasts and spongioblasts. They are simple ciliated cells that are found lining the canal of the spinal cord and parts of the ventricles of the brain. The basal ends of the cells are usually branched; these branches extend into the surrounding gelatinous substance where they soon disappear. These cells multiply in the adult body and tend to occlude the spinal canal in part or as a whole.

The *astrocytes* are usually stellate elements with many processes. The *mossy cells* are those in which the processes are short and thick and are found chiefly in the gray nerve tissue. In some of the cells the processes are dendritic and do not extend far from the cell. The *spider cells* have fewer but longer processes and are found mainly in the white nerve tissue. These cells are both small and large; the smaller ones show merely a rim of cytoplasm around the deeply staining nucleus. In the larger cells the cytoplasm is greater in quantity and the processes are said to be more numerous.

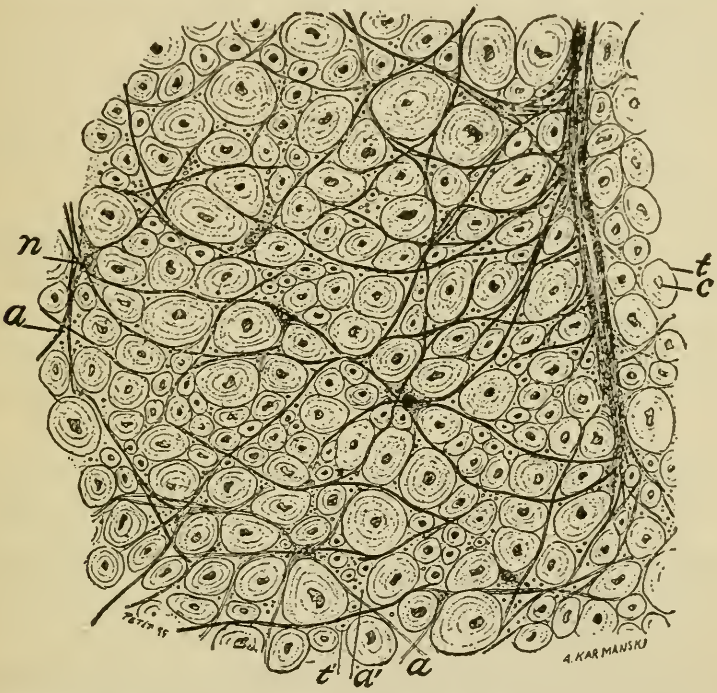


FIG. 101.—CROSS-SECTION OF SPINAL CORD SHOWING GLIAL FIBERS AMONG THE NERVE FIBERS.

a, *a*, Glial fibers; *a'*, same cut across; *n*, body of glial cell; *t*, cross-section of a myelinated nerve fiber; *a*, axone of same; *t'*, small (sensor?) nerve fiber. (*Schäfer after Ranvier.*)

The *glial fibers* are delicate filaments of protoplasm that form a network for the support of the nerve cells and glial cells. Some of the fibers have a very intimate relation with the glial cells passing close to the cell-body or even through its peripheral cytoplasm although they are distinct from the cell-body.

According to the investigations of Hardesty the glial fibers appear late, that is after some of the nerve fibers have become myelinated and long after the first connective tissue fibers have appeared. They are formed in the neural syncytium (*neurospongium*) in which they are formed directly by the cells or through their activity.

The **white nerve substance** of the central nerve system consists of myelinated nerve fibers supported by neuroglia and some white fibrous connective tissue; the latter is chiefly for the support of the blood-vessels. In the *peripheral nerves* the supportive substance is white fibrous tissue.

After the axone of a cell of the first type leaves the cell it becomes a nerve fiber. If the axone becomes invested with a myelin sheath it is then a myelinated nerve fiber such as constitute the cerebrospinal system. If no myelin sheath is present it is then called an amyelinated nerve fiber, as is seen in the sympathetic nerve system.

An **amyelinated,** or **nonmedullated nerve fiber** (*Remak's fiber*) consists of an axis cylinder surrounded by a delicate sheath called the neurolemma, and is said to be connected exclusively with the sympathetic nerve system. Ransom, however, found that these fibers were more numerous in the ordinary nerves than had hitherto been supposed. These fibers are very numerous in the spinal nerves, and in the vagal nerves of the dog the amyelinated fibers predominate caudal to the diaphragm; these fibers are both efferent and afferent.

The *axone* arises at the axis cylinder hillock and consists of a bundle of neurofibrils imbedded in apparently homogeneous neuroplasm. It is continuous in its course and terminates in a set of branches called *teleneurites*. These sympathetic axones are the smallest measuring from 1.8 to 3.6 microns in diameter. The neurofibrils seem to converge from the dendrites to the axis-cylinder hillock. Although some investigators claim that these neurofibrils branch and interlace in the nerve fiber most observers hold that they are individual throughout their course. These fibers are semi-solid and readily become varicose. Under high magnification each fibril seems to be tubular in character, the center of the tubule begin filled with the fluid *conductive substance*, as pointed out by Carlson. Surrounding the axone there is a delicate sheath that may be more pronounced in places and contain nuclei. This is the *neurolemma*. It is not always well developed and its nuclei appear to be imbedded in the peripheral portion of the axone.

The amyelinated nerve fibers are grayish in color. They terminate in the smooth muscles of the various organs (including the heart) and upon the epithelial cells of mucous membranes and glands. These fibers are also seen in several of the cerebral nerves and the ventral roots of the thoracic, most of the lumbar and some of the sacral spinal nerves. Through these they go to or come from the various organs and structures to which these nerves are distributed.

Amyelinated nerve fibers without a neurolemma consist of merely a naked axis cylinder. The fibers of the olfactory nerves belong to this class. Here are also placed the proximal and distal parts of the myelinated type that have as yet not become invested with this sheath or have lost it. It seems that this is a very trifling distinction as no myelinate nerve fiber receives its sheath directly upon arising from the cytom nor does the sheath ever continue to the termination of the axis cylinder.

A **myelinated,** or **medullated nerve fiber** is white in color and forms the bulk of the white nerve tissue of the cerebrospinal system; some of this variety are found even in sympathetic nerves. This type of fiber consists of axone, myelin sheath and neurolemma. The *axone* consists of a bundle of neurofibrils imbedded in a mass of homogeneous neuroplasm, apparently surrounded by a delicate membrane called the *axilemma*. The presence of this membrane is denied by some. These fibrillæ are probably the conductive parts of the fiber though some are inclined to believe that the neuroplasm only has this property. The fibrils in mammals are very fine and almost evenly distributed in the axone although occasionally a narrow peripheral clear zone may be found. In lower animals the fibrils are coarser and tend to form a mass in the center of the axone with a resulting clear peripheral area. The fibrils are considered by some merely a support for the neuroplasm. The largest axones (to the skeletal muscles) are 8 to 16 microns in diameter, though sensor fiber may be as small as 4 microns in diameter.

The *myelin*, or *medullary sheath* (*white substance of Schwann*) is, apparently an insulating sheath found mainly in the cerebrospinal system. This sheath is not continuous but is interrupted at regular intervals called the *nodes of Ranvier*. In fresh nerve fibers this sheath is homogeneus. After fixation it consists of a *reticular substance* and the *myelin*. The *former* is composed of *neurokeratin* and is arranged in the form of a network that is invisible in fresh nerves. It seems to be a coagulation product as the meshes of the reticulum vary in size according to the strength of the reagent used.

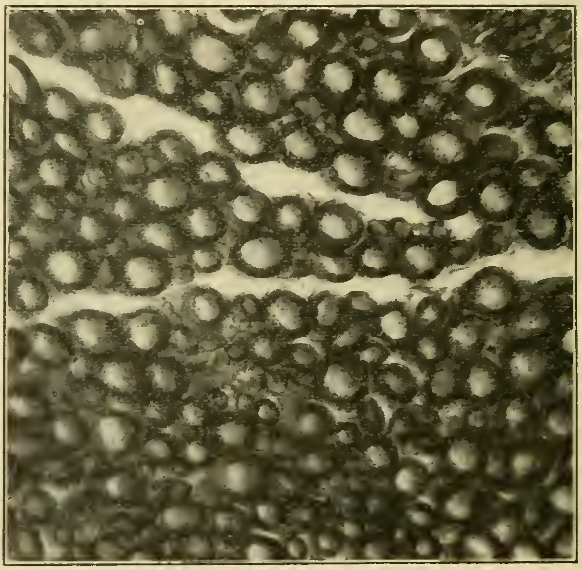


Fig. 102.—Cross-section of Osmicated Nerve. (Photograph. Obj. 16 mm., oc. 10 X.)

Alchohol and ether produce the best results and these results may be obtained with isolated myelin. Picric acid produces a different coagulation effect. When this agent has been used and transverse sections are made the myelin sheath has the appearance of fine delicate rods radiating from the axis cylinder to the neurolemma. The myelin substance is a phosphorized fat that is practically liquid at the ordinary temperatures for if the neurolemma of a fresh fiber be ruptured the myelin oozes out in the form of droplets. This substance responds readily to osmic acid solutions which turn it black, thus showing the presence of a fatty substance. It is also readily soluble in ether. It is probably nutritive in function.

In the degeneration of nerve fibers the myelin sheaths show the first signs. This is of importance in the study of diseases of the nerve system and in tracing the fiber tracts.

At regular intervals the myelin sheath is interrupted and the neurolemma dips into the axis cylinder. These regions are the *constrictions of Ranvier* and because the myelin sheath at these points may be somewhat bulbous, giving a nodal appearance, they are also called the *nodes of Ranvier*. These are seen only in longitudinal sections of osmicated nerve fibers. If a nerve fiber be treated with nitrate solution (Ranvier's method) the solution penetrates at these nodes and makes a +-like stain. Those portions between the nodes are called the *internodes*. In osmicated preparations oblique, cleft-like spaces are numerous; these are the *clefts of Lantermann* (*lines of Schmidt-Lantermann*). The intervening parts of the sheath are the *medullary segments*. What they represent is still unsettled.

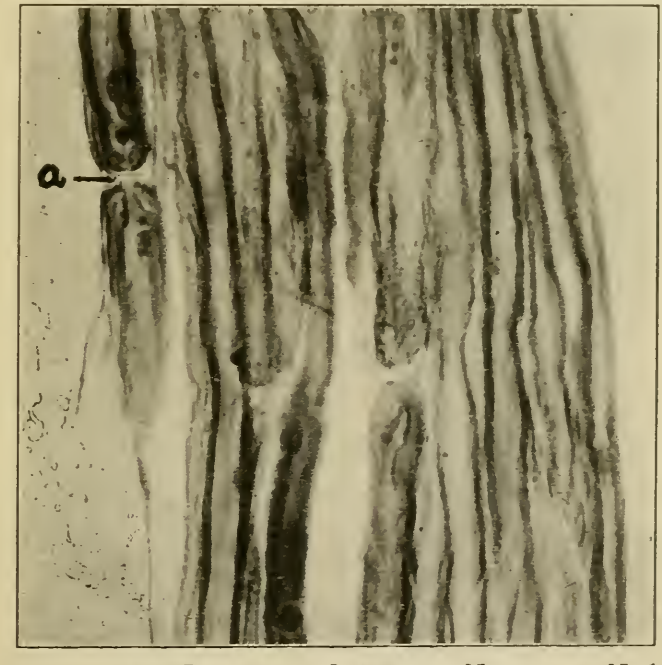


FIG. 103.—LONGITUDINAL SECTION OF OSMICATED NERVE. *a*, Node of Ranvier. (Photograph. Obj. 4, mm. oc. 5 ×).

The *neurolemma, or sheath of Schwann* is the delicate sheath that limits the fiber. This is a thin, homogeneous membrane and in each internode there is a nucleus. Although the sheath seems continuous over the nodes it is though that it really ceases here and that the successive nucleated segments, constituting individual cells, are connected by intercellular cement, as is seen in epitheliod cells. This sheath probably represents specialized ectodermal cells of the neural tube.

This type of nerve fibers is found in the peripheral nerve system.

Myelinated nerves without a neurolemma are found in the brain and spinal cord. All of the white substance consists of nerves of this type. In these fibers the myelin sheath possesses no nodes of Ranvier and so continues uninterruptedly. Sheath cells are present and these are said to assist in the production and maintenance of the myelin. Myelinated nerve fibers conduct impulses more rapidly than the amyelinated fibers.

THE PERIPHERAL NERVE SYSTEM

The peripheral nerve system comprises the nerves and the ganglia connected with the spinal and the sensor cerebral nerves.

A **nerve** or **nerve trunk** consists of a variable number of nerve fibers collected into a compact mass and bound together by various sheaths. Upon the outside is a sheath of loose areolar tissue called the *epineurium*. This contains the larger vessel and lymphatics and also the nervi nervorum, the sensor nerves of the nerves. The epineurium is usually thin and sends in septa (for the support of blood-vessels) that divide the nerve into large secondary bundles; from these septa others extend in to surround individual bundles of nerve fibers called funiculi. The sheath surrounding each funiculus is called the *perineurium* and this is usually thicker in proportion than the epineurium. Although the perineurial sheaths seem compact their layers are readily separable from one another, indicating extensive tissue or lymph spaces that are continuous with the spaces around the brain and spinal cord. By this means the cerebrospinal fluid may pass into the nerves toward the periphery (Keyes). From the perineurial sheath bundles of fibers pass into each fasciculus forming here a delicate reticulum (*endoneurium*) which supports not only the nerve fibers but also the capillaries that nourish the nerve trunk. The endoneurium may even form partial septa.

The funiculi as well as the nerves vary greatly in size. A nerve, as the optic nerve, may consist of a single funiculus comprising 450,000 to 800,000 fine nerve fibers, or it may consist of many funiculi but few fibers, as the vagal nerve with its 10,000 nerve fibers. The nerve fibers in a funiculus rarely branch but the fibers themselves may start in one funiculus and cross over and join another. When a single nerve fiber runs individually to an organ it is usually surrounded by a delicate sheath derived from the perineurium, called the *sheath of Henle*.

Nerves are quite vascular. The *large arteries* enter the epineurium and divide into branches that pass to the septa between the secondary bundles; from here branches are sent into the primary fasciculi where the arterioles form an extensive capillary plexus in the endoneurium. The blood is collected by the venules in the endoneurium and from here is conducted by small venous channels that lie along side of the arterial channels.

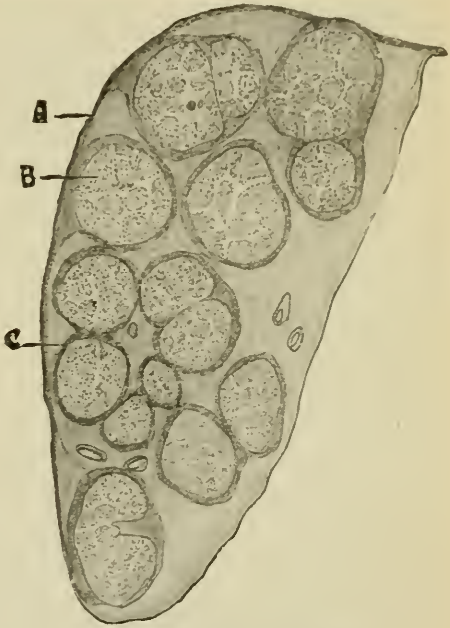


FIG. 104.—CROSS-SECTION OF A HUMAN SCIATIC NERVE.

A, Epineurium; *B*, funiculus of nerve fibers; *C*, Perineurium. (*Radasch, Reference Handbook of the Medical Sciences.*)

The *lymph spaces* of the nerve are very extensive as has been mentioned. Perivascular lymph vessels are said to be numerous in the epineurium and larger septa.

The *nervi nervorum* are numerous and small. They supply the blood-vessels (sympathetic) and some are sensor in function. The presence of the latter nerves is denied by some.

A **ganglion** is an isolated mass of nerve tissue in the course of a sensor nerve. Some consist of merely a few nerve cells and are, therefore, microscopic; others are quite large and are easily found and recognized. The cerebrospinal ganglia all have the same general structure.

A **ganglion** consists of a sheath or *capsule* of white fibrous tissue that supports the structures within and serves to delimit it from the surrounding structures so that it may be readily isolated. This sheath sends in trabeculæ that form a delicate network in which are found the ganglion cells, myelinated and amyelinated nerve fibers, blood-vessels and lymphatics. The *cells* of the cerebrospinal ganglia are usually ovoid, or round and of the unipolar, or bipolar type. The unipolar cell is now looked upon as bipolar as the single process is considered merely an extension of the cytoplasm and not a mere process. The cells of the vestibular and cochlear ganglia of the acoustic nerve retain their bipolar character throughout life. The nerve cell is surrounded by a *lymph space* that is limited by a single layer of flattened epithelioid cells that is extended upon the processes and is continuous with the neurolemma. The spaces and capsules are absent in the vestibular and cochlear ganglia.

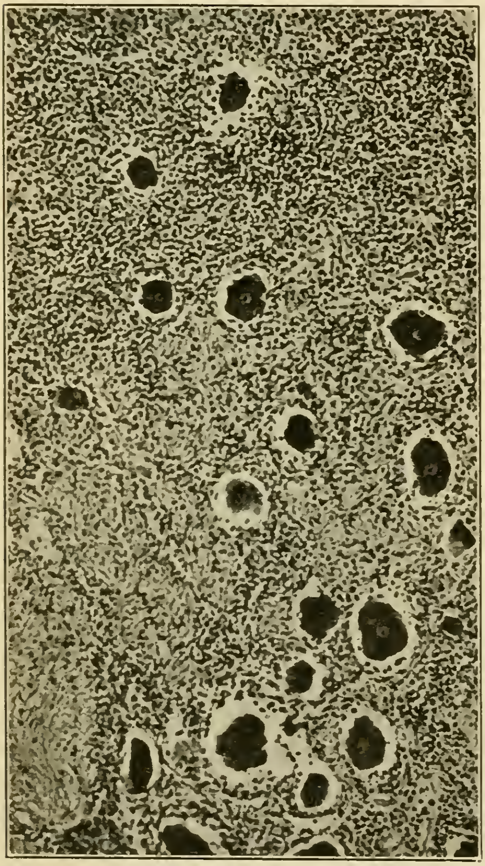


FIG. 105.—SECTION OF SEMILUNAR GANGLION OF A HORSE. The nucleolus shows up well in several of the cells. (Photograph. Obj. 16 mm., oc. 7.5 X.)

There are *three types or varieties of cells in the spinal ganglia:* (1) Large unipolar cells with thick processes that branch Y- or T-like become myelinated and leave the ganglion (first type cells).

(2) Cells of the second type in which the delicate axones remain in the ganglion and divide into fine branches that penetrate the epitheliod capsules and terminate about the previous cells. (3) Small cells of pyriform shape the process of which divides and leave the ganglion as in the first variety. The processes of these last cells do not become myelinated however and Ransom believes them to be efferent in function. These amyelinated fibers are the ones previously mentioned as components of spinal nerves. In lower animals these last cells constituted, according to Ransom, two-thirds of the cells of the ganglion. A few multipolar cells are found in ganglia of the adult according to Dogiel.

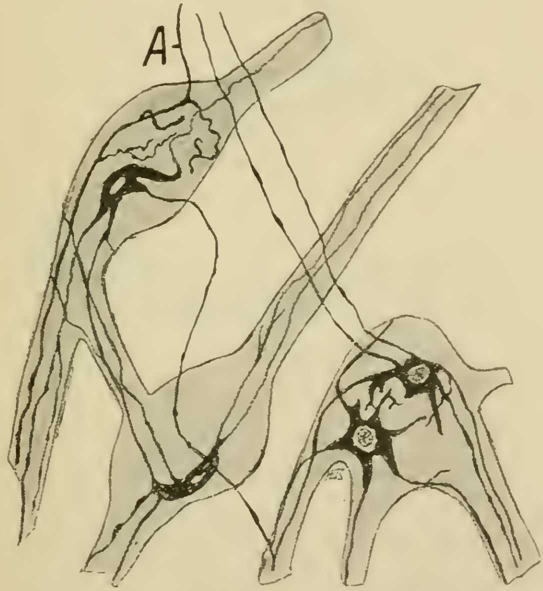


Fig. 106.—Three Small Ganglia of the Submucous Plexus. *A*, A nerve fiber passing through one of the ganglia but giving off collaterals to it. (*After Cajal.*)

The *nerve fibers* are myelinated and amyelinated. The former are afferent and efferent. The *afferent fibers* come from the outside and terminate in the ganglion in delicate branches that penetrate the capsules of the cells and form an arborization about the bodies of the ganglion cells. The *efferent fibers* are those that arise from the first type cells (1 and 3). In the case of the axones of cells (1) they form a convoluted mass before leaving the cell capsule and after passing through the capsule soon become myelinated. The axones of cells (3) run a straight course and do not become myelinated. Other amyelinated fibers are those of the sympathetic system and the axones of cells (2).

In **sympathetic ganglia** the cells are multipolar in form. There are two types of cells. (1) Large spherical elements that possess from 1 to 16 dendrites. The axones of these cells pass to a nerve as a nonmedullated fiber but may later receive a delicate myelin sheath. These are considered sensor in function. The dendrites are slender, long, enter the nerve and probably pass to a neighboring ganglion. (2) Smaller stellate, or spindle-shaped cells with 5 to 20 dendrites. The axone is also amyelinated when it enters the nerve but may later receive a delicate myelin sheath. The dendrites are short and thick and form synapses about other cells of the same ganglion. These are motor cells. The corpuscles of Nissl are of medium size and are grouped near the periphery of the cell.

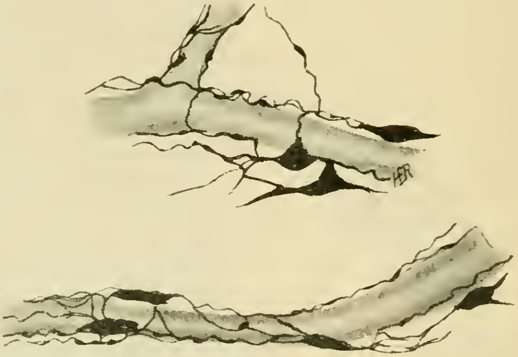


Fig. 107.—Perivascular Terminal Nerve Plexuses of the Sympathetic Nerve System. (*After Dogiel.*)

The fibers in a sympathetic ganglion are both myelinated and amyelinated. The *former* are derived from the cerebrospinal system and constitute the white rami communicantes while the *latter* are the sympathetic fibers proper.

Sympathetic nerves have the same general structure as those of the cerebrospinal system but the sheaths are usually thinner and the nerves smaller. In the larger nerves are found many myelinated fibers that are derived from the cerebrospinal system.

Degeneration and Regeneration of Nerves.—If a living nerve be cut union between the cut parts is reëstablished by cicatricial tissue but the cut fibers themselves do not unite. The peripheral or distal portion of the process undergoes degeneration within twenty-four hours after the lesion, in warm-blooded animals but the changes are later in cold-blooded animals. The neurolemma becomes quite distinct, its nuclei increase in size; the myelin sheath undergoes changes and droplets of fat become abundant. The axis cylinder undergoes disintegration and disappears. The myelin is almost entirely removed (probably by the action of phagocytes) but fatty granules in the neighboring cells increase and stain more deeply with osmic acid solution than the normal myelin. This process is not limited to one part of the axone but occurs along its whole length at the same time. This change occurs earlier in the motor than in the sensor nerves.

The proximal portion (cell end) of the axone does not degenerate but regenerates. After the lesion the cut end usually becomes slightly swollen. The regeneration process is slow as changes are not noticed until nearly two months have elapsed. If the nerves be then removed and sections made then the old neurolemmal tubes will be found to contain new axones, and new fibers, individual or in groups, are seen between these. These *new fibers* may be amyelinated or possess a thin myelin sheath. These fibers are seen to be continuous with the proximal ends of the original nerve fibers. The small groups noted may be the outgrowth of only one axis cylinder, or only one or two may arise from one axone but these will then branch and rebranch until quite a number has been formed. As a result there are more fibers in the healed nerve than in the original condition. The new fibers arise from the old one near a node and may enter the old neurolemmal sheathes or be independent of these. In the latter case they are at first amyelinated and later become myelinated and receive a neurolemma. The growing cut ends of the axones are bulbous and resemble the growing axonic process of the neuroblast. As this growth is slow, the function of the nerve is not resumed for many months after the lesion and only a few of the many new fibers assume the function of the fibers cut.

The new axones that do not enter the old sheath have a very irregular course. This is probably due to the fact that they have no original path to follow and must sort of seek their way. Regeneration occurs more quickly if the cut ends are placed in apposition. If a gap is left the process is slower. If a piece of the nerve be removed and the cut ends cannot be brought together then a piece of *guide material* should be placed in the gap. The best material is a piece of aseptic, dead nerve (Huber).

NERVE ORGANS

Nerve fibers terminate either in the form of telodendrites (free) or in some special structure called a *nerve organ;* these may be comparatively simple or very complex. There are two varieties of organs **sensor** and **motor.**

The **sensor organs are free, tactile cells, corpuscles** and **spindles.**

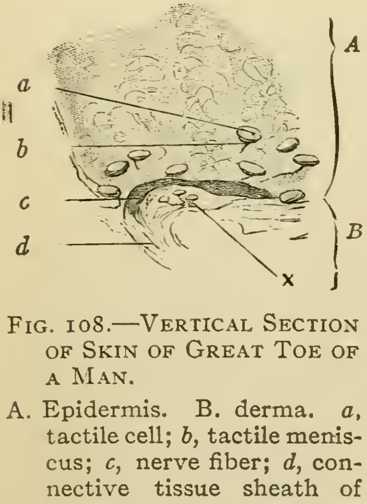


FIG. 108.—VERTICAL SECTION OF SKIN OF GREAT TOE OF A MAN.

A. Epidermis. B. derma. *a*, tactile cell; *b*, tactile meniscus; *c*, nerve fiber; *d*, connective tissue sheath of same; *x*, tactile cells in derma. (*Stöhr's Histology.*)

The **free terminals** are found in mucous membranes (especially in stratified epithelium), serous membranes, cornea, skin and intermuscular connective tissue. As the myelinated nerve fibers approach their termination they branch. In the epithelial structure when the basement membrane is reached the neurolemma and myelin sheathes disappear and the naked axone enters the epithelial layer. In this the terminal fibrillæ, which are usually varicose, end in leaf-like expansions, or bulb-like enlargements upon the epithelial cells but not within them. In serous membranes and in the intermuscular septa the fibrils end in flattened expansions.

Tactile Cells Are Simple and Compound.—The simple variety consists of modified epithelial cells, each of which is composed of a disc-like structure, 6 to 13 microns in diameter, and a mass of clear cytoplasm. In each *disc* a naked nerve fiber (dendrite) terminates. These structures are found within the interpapillary portions of the epithelium of the skin and in the root sheaths of the hairs.

The **compound tactile cells** consist of two or more discs containing between them tactile cells which are nucleated masses of granular protoplasm. See *Grandy's Corpuscles.*

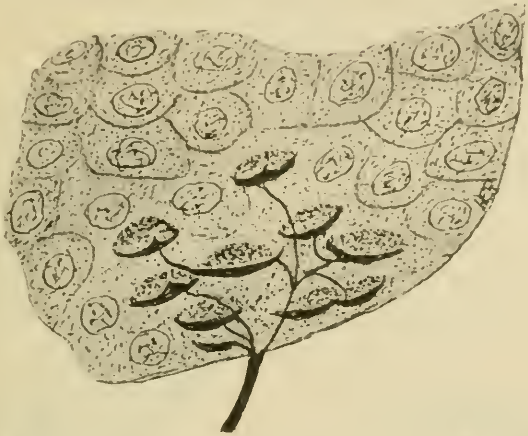


FIG. 109.—SIMPLE TACTILE CELLS IN THE EPITHELIUM OF A PIG'S SNOUT. (*After Ranvier*).

The **tactile corpuscles** or **bulbs** are the more differentiated of these organs. They vary in complexity from the comparatively simple genital and conjunctival corpuscles to the more complex corpuscles of Meissner and Vater.

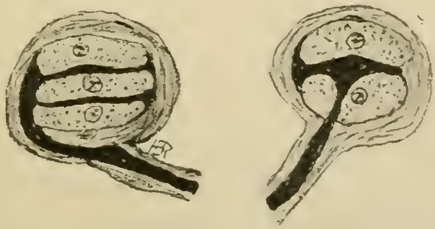


FIG. 110.—COMPOUND TACTILE CELLS, WITH TWO AND THREE CELLS, FROM A DUCK'S TONGUE. (*After Izquierdo.*)

The **conjunctival corpuscles** or **bulbs** are spherical, oval, or pear-shaped bodies in which the cells are not regularly arranged. The nerve fibers, upon piercing the structure become amyelinated and pass through a central core of homogeneous protoplasm and terminate in a bulbous manner. The *core* is surrounded by a *capsule* that is composed of flattened cells. These organs average from 60 to 400 microns in length and may have as many as 10 nerve fibers connected with one organ.

The **genital corpuscles** or **bulbs** are more complex. Each is divided into two to six knob-like parts. The nerve fiber enters the organ and divides into numerous branches each of which passes to a *segment;* here it may continue undivided, or form a series of branches. These are surrounded by the capsular cells. These measure from 60 to 400 microns in length and 40 to 100 microns diameter. They are found in the mucosa of the glans penis, glans clitoris and neighboring structures.

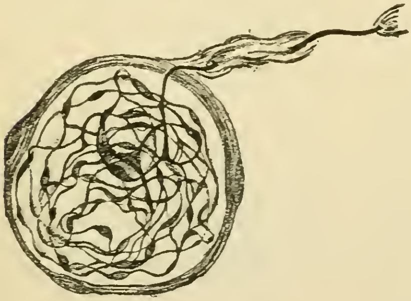


FIG. 111.—BULBOUS CORPUSCLE FROM THE HUMAN CONJUNCTIVA. METHYLENE BLUE STAIN. (*After Dogiel, from Böhm and Von Davidoff.*)

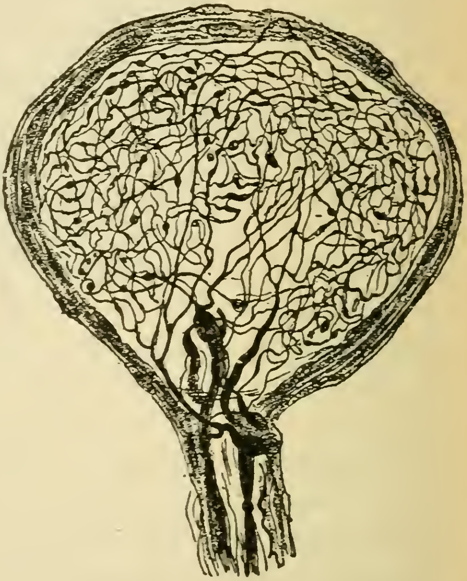


FIG. 112.—GENITAL CORPUSCLE FROM THE HUMAN GLANS PENIS. METHYLENE BLUE STAIN. (*After Dogiel, from Böhm and von Davidoff.*)

Other end bulbs both simple and complex are found in the peritoneum, around joints, in tendons and ligaments and even in nerves.

The **corpuscles of Ruffini** are cylindrical structures consisting of a *central core* of connective tissue, or according to some, granular material. This is surrounded by a *sheath of connective tissue.* The nerve fiber usually enters from the side, loses its sheath of Henle and within the structure becomes a naked process that forms a close ramification of fibrils around the connective tissue bundles, or in the granular material. One original nerve fiber may supply a number of these organs. These are found in the deeper portion of the stratum reticulare of the skin and are about as numerous as the Pacinian corpuscles.

The **corpuscles of Golgi-Mazzoni** are cylindrical, or spherical organs and consist of a large granular *core* surrounded by a *capsule* of connective tissue that consists of a number of layers. As the nerve fiber penetrates the structure the sheaths blend with the capsule and the naked process enters the granular core and divides into a number of branches that terminate in flattened expansions. These are found in the derma of the external genitalia, the fingers and in the periosteum and conjunctiva.

The **corpuscles of Grandy** are really *compound tactile cells.* Each consists of a *capsule* of white fibrous tissue surrounding two or more *tactile epithelial cells.* These cells are flattened and their cytoplasm is striated. Between the cells are the *tactile discs.* When the nerve fiber enters the organ the sheaths are lost upon entering or by the time it has passed through the capsule. The naked axone then divides into as many branches as there are discs and one branch ends in each disc in a series of fibrils, which according to Dogiel, enter the adjoining cells. These organs are found only in the aquatic birds.

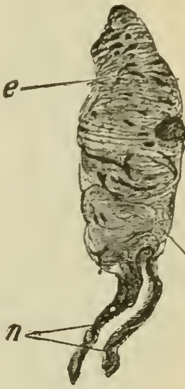


FIG. 113.—CORPUSCLE OF MEISSNER FROM GREAT TOE OF MAN.

n, Myelinated nerve fiber; *h*, connective tissue sheath; *e*, varicosities. The nuclei are invisible. (*Stöhr's Histology.*)

The **corpuscles of Herbst** resemble somewhat the Pacinian corpuscles. Each consists of a *capsule* in which the outer layers run longitudinally and the inner ones transversely. The *core* is composed of transversely placed cells and it is traversed by the naked axone. These organs are found in the cere of aquatic birds.

The **tactile corpuscles of Meissner** are more complex. Each measure about 100 to 180 microns in length and 35 to 50 microns in diameter. It consists of a *capsule* of white fibrous connective tissue that encloses a number of flattened masses of protoplasm with transversely placed nuclei. One or more nerve fibers is connected with each organ and upon contact with the corpuscle the neurolemma is lost. The myelin sheaths soon leave and the naked axones, after a spiral course, divide into a number of varicose fibrils that form a network and then terminate in small bulbous enlargements near the capsule. These are found throughout the skin of the body but are most numerous in the derma of the palmar surface of the finger tips (as many as twenty to the square millimeter). They are also found in the derma of the plantar surface, in the nipples, lips, glans clitoris and penis and the conjunctiva. They convey sensations of pain, pressure, warmth and cold. It is said that two sets of sensor fibers enervate them, one for light pressure and light temperature changes and the other for pain and extreme temperature changes.

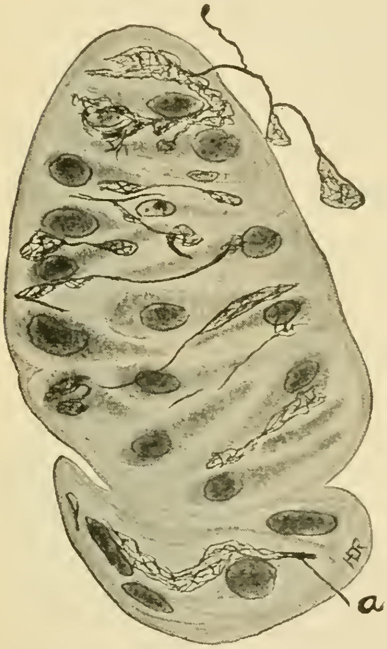


FIG. 114.—A TACTILE CORPUSCLE WITH ITS CELLS AND TERMINAL NEUROFIBRILS. *a*, Axone. (*After Van de Velde.*)

Pacinian corpuscles (Vater) are also called **lamellar corpuscles.** Each consists of a *capsule*, *inner bulb* and *end knob*. The *capsule* consists of lamellæ of connective tissue concentrically arranged and which are usually bound together by an *intracapsular ligament*. These lamellæ are from forty to sixty in number and the outer ones are more widely separated from one another than the inner ones. Each lamella is said to consist of both white fibrous and elastic tissues and is covered upon both surfaces by endothelial cells forming a series of lymph spaces.

The *inner bulb*, or *core*, is a cylindrical mass of protoplasm that may show striations and nuclei. It is thought to consist externally of flattened nucleated cells surrounding the more homogeneous central portion. A single nerve fiber enters each corpuscle. As it pierces the capsule the neurolemma blends therewith and the myelin sheath is lost when the inner bulb is reached. The naked axone, showing its fibrillation, in properly stained sections, passes through the core at the end of which it expands into knob-like structure, the *end knob*. In this the terminal fibrils form a very dense meshwork. If the axone divides in the core the latter also divides. A small amyelinated nerve fiber has been found by Solokoff, passing to the core and terminating upon it in a reticular manner.

A *small artery* and *vein* accompany the nerve into the corpuscle. The artery forms capillary vessels that form loops between the lamellæ; one capillary accompanies the inner bulb and courses along the outer surface of this for a variable distance. The blood is returned by a small vein that leaves at the nerve entrance.

These organs are visible to the unaided eye, measuring usually 2.5 mm. in length and 1 mm. in diameter. They are found in the deep part of the derma, along tendons, around joints, in the peritoneum, in the mesentery (especially in lower animals) and in the pancreas of the cat.

Muscle Spindles.—These organs are spindle-shape and consist of from 4 to 20 small voluntary muscle fibers, the *intrafusal fibers*, surrounded by a delicate white fibrous sheath called the *axial sheath*. External to this is the *capsule* composed of about six layers of white fibrous connective tissue concentrically arranged and separated from the axial sheath by a lymph space. In the equatorial region of the organ the muscle fibers consist chiefly of sarcoplasm and the striations are faint, while at the ends the striations are quite distinct. The muscle fibers are said to pass into tendon fibers at their ends and these fibers may continue into the intramuscular tissue, or if the spindle be near the tendon end of the muscle the fibers become continuous with those of the tendon. One or more nerves enter the organ near its equator and branch just inside of the capsule; these lose their sheaths and wind about the intrafusal fibers in the

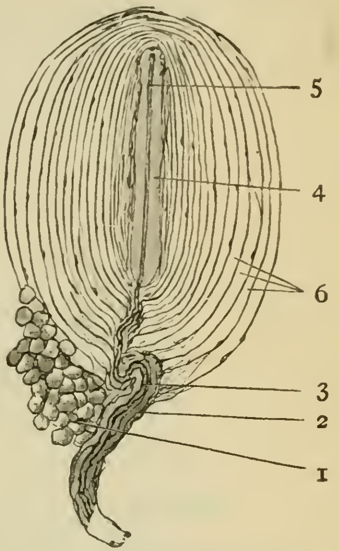


FIG. 115.—PACINIAN BODY FROM MESENTERY OF A CAT.

1. Fat cells; 2, artery; 3, nerve fiber; 4, inner bulb; 5, axis cylinder; 6, layers of the capsule. (*Stöhr's Histology*.)

form of rings or spirals or may form a series of telodendrites. These all terminate in *flower-spray endings* upon the surface of the various intrafusal muscle fibers. Although these terminations resemble motor terminals they are sensor. Motor terminals have been demonstrated in these muscle fibers.

The spindles are numerous in some muscles (small muscles of the hands and feet), few in others (eye muscles), and absent in others. They measure from 1 mm. to 5 mm. in length and 0.1 mm. to 0.2 mm. in diameter. Each has its own blood-vessels that accompany the nerve through the capsule.

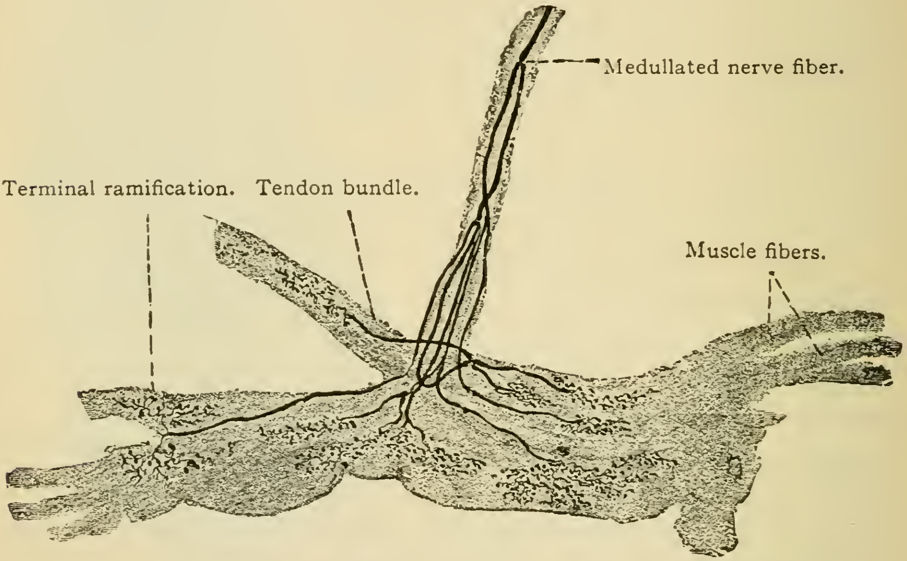


FIG. 116.—TENDON-SPINDLE OF A CAT. (*Stöhr's Histology.*)

Tendon spindles resemble muscle spindles except that the intrafusal fibers are tendon fibers and the naked axones do not wind around the intrafusal fibers but branch into minute fibers that terminate in little plates upon the tendon bundles. They are most numerous near the junction of the muscles and tendons.

The **motor terminals** comprise those in voluntary striated muscles, those of smooth and of cardiac muscle tissues and those of glands.

The nerves of the *voluntary striated muscles* are of the myelinated type and are comparatively large. After passing through the epimysium the nerve divides into branches that form a plexus in the perimysial sheaths. From this plexus fibers enter the fasciculi and form a plexus in the endoneurium. As such a nerve does not contain as many fibers as there are muscle fibers, usually, the fibers that are derived from the endomysial plexus give off branches or collaterals so that there will ultimately be as many nerve fibers as there are muscle fibers. As this terminal nerve fiber pierces the sarcolemmal sheath the neurolemma and myelin sheath blend with the sarcolemma and the naked axis cylinder alone enters the muscle fibers. This passes to the *sole-plate* which is a mass of granular, nucleated protoplasm. Within this the fibrillæ of the nerve fiber terminate

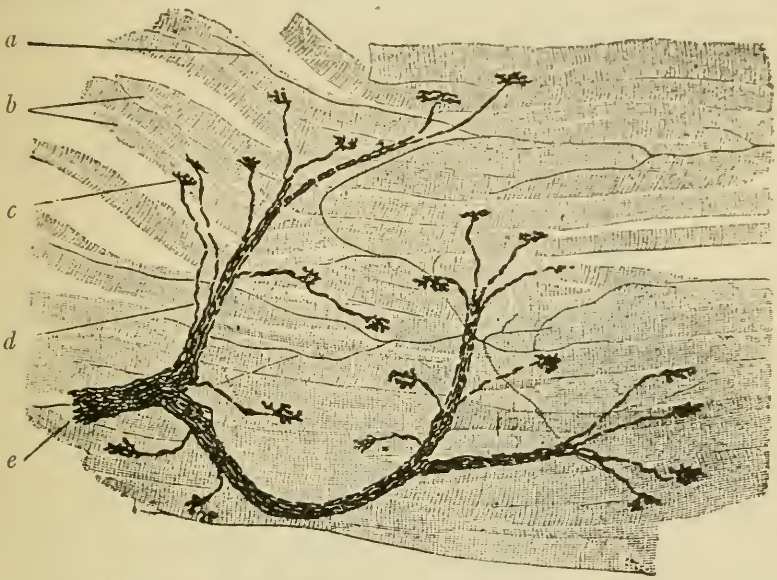


FIG. 117.—MOTOR NERVE-ENDINGS IN INTERCOSTAL MUSCLE OF A RABBIT. *a*, Sensor nerve fiber; *b*, muscle fibers; *c*, motor plates; *d*, myelinated nerve fiber; *e*, bundle of nerve fibers. (*Stöhr's Histology.*)

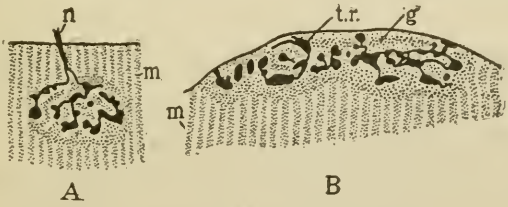


FIG. 118.—MOTOR PLATES.

A, Surface view, from a guinea-pig. *B*, Vertical section, from a hedgehog. (*After Böhm and von Davidoff*). *g*, Granular substance of the motor plate; *m*, striated muscle; *n*, nerve fiber; *t.r.*, terminal ramifications of the nerve fiber.

in bulbous enlargements, which, with the sole-plate constitute the *end-plate.* There is but one organ to each muscle fiber.

The *smooth muscles* are supplied by the sympathetic nerves. These form plexuses between the fasciculi or muscle layers and at the intersections of the meshes ganglion cells are to be found. Fibers (amyelinated) from this plexus may form a secondary plexus in between the muscle fibers and from this the terminal fibers pass to the muscle cells. Here they end as *tapered*, or *bulbous extremities* that are applied to the surface of the muscle cells. Some of the fibers of smooth muscle are of sensor function.

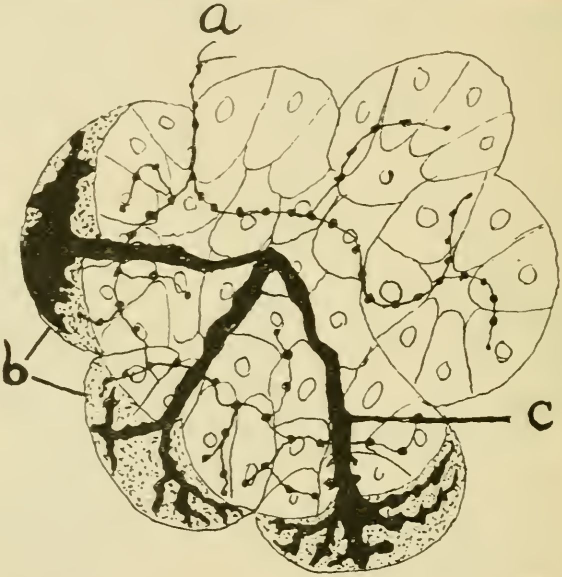


FIG. 119.—TERMINATION OF SECRETOR NERVE FIBERS IN THE TUBULES OF THE SUBMAXILLARY GLAND OF A DOG. (*After G. Retzius.*)

Cardiac muscle is also supplied by the sympathetic system. The fibers may form delicate plexuses at the intersections of which are found ganglia of various sizes. Individual amyelinated nerve fibers pass to each muscle cell and terminate upon its surface in many fine fibrils that spread over each nucleated segment or cell. Some of the fibrils may terminate in small granules or knobs.

In *secreting glands* the nerve fibers are amyelinated and arise in sympathetic ganglia. In the gland the nerve fibers pass to the secreting epithelium, divide into fibrils each of which terminates in a varicose manner between and upon the cells but does not pass into the cells. These are the *secretor fibers.*

CHAPTER VII

CIRCULATORY SYSTEM

The **circulatory system** comprises the **heart, arteries, capillaries, veins** and the circulating fluid, the **blood.**

THE HEART

The **heart** is the most important member, as on its contractions depends the circulation. It is a thick-walled, hollow, muscular organ composed of three coats, the **endocardium, myocardium** and **epicardium.** These three coats are analogous to the coats of the vessels. Of these three the one that continues with the least change throughout the vessels is the internal coat; of this the endothelial layer continues in an unbroken line through the arteries, capillaries and through the veins back to the heart. The walls of the chambers have not all the same thickness and this is due to the different quantity of muscle tissue present. The reason for this difference is that in the two sets of chambers the muscular effort required of them is not the same.

The **endocardium** consists of a lining of *endothelial cells* which rest upon the *subendothelial* (fibro-elastic) *tissue.* It is thicker in the atria than in the ventriculi. Although the endocardium is smooth, glistening and transparent it does not always run an even and smooth course as in the blood-vessels as in parts of the chambers the myocardium is very irregulary arranged. The endocardium lines every part of these chambers, covers the valves and chordæ tendineæ and is continuous with the intima of the vessels of the heart.

The *endothelial cells* are flattened, nucleated plates that have an irregular outline and are held together by a small amount of intercellular cement. They differ but slightly from those found within the vessels. The layer of cytoplasm may be so thin that the nuclei project somewhat.

The subendothelial tissue consists of delicate fibroelastic tissue. The outer part of this layer (next to the myocardium) contains less elastic tissue and the fibers are usually coarse. Frequently fat is found here. It may contain a few involuntary nonstriated muscle fibers. Here also are seen some partly developed heart muscle fibers, called *Purkinjé fibers;* the fibrillæ are few and form a peripheral ring in these muscle fibers. They are common in some mammalian hearts, and in man they are represented by the terminals of the **Bundle of His.**

Over the chordæ tendineæ and papillary muscles the endocardium is very thin and the elastic tissue is less in amount.

Guarding the atrioventricular orifices and the openings into the pulmonary artery and aorta are duplications of the endocardium called **valves.** Around the openings the fibroelastic tissue is condensed to form a ring-like mass, the **annuli fibrosi.** These rings serve as origins for the valves and muscle. In the larger quadrupeds cartilage may be present.

The **atrioventricular valves** consist of two layers of endocardium continuous at the free edges of the valves; the central part consists of a layer of tough white fibrous tissue containing but few elastic fibers. This central tissue is continuous with the rings and the chordæ tendineæ. At the bases of the valves there is a considerable quantity of smooth muscle tissue which may act as a *constrictor of the orifice.* The atrial muscle may extend for a short distance into the atrioventricular valves.

The *chordæ tendineæ* consist of cords of white fibrous tissue surrounded by a thin layer of the endocardium. Above they are attached to the valves where the endothelial surface becomes continuous with that of the valve and the central cord fibers pass to the central fibrous mass of the valve and join it in a radiating manner. Below they are attached to the papillary muscles where the endothelial surfaces are continuous and the central fibers blend with the endomysium of the papillary muscles.

The **semilunar valves** have the same general structure. They differ in several ways. No chordæ tendineæ are present and each valve possesses a *marginal band*, under the endocardium, in the middle of which there is an enlargement, the *corpus Arantii.* At each side of the corpus there is a small semilunar fold called the lunula. The band strengthens the free edge of the valve while the nodule probably ensures complete closure of the valves. These valves are thinner than the atrioventricular valves. The atrial myocardium may continue into their bases. Blood-vessels extend into them as far as the muscle tissue penetrates. The aortic valves are more elastic on the ventricular surface than upon the aortic surface.

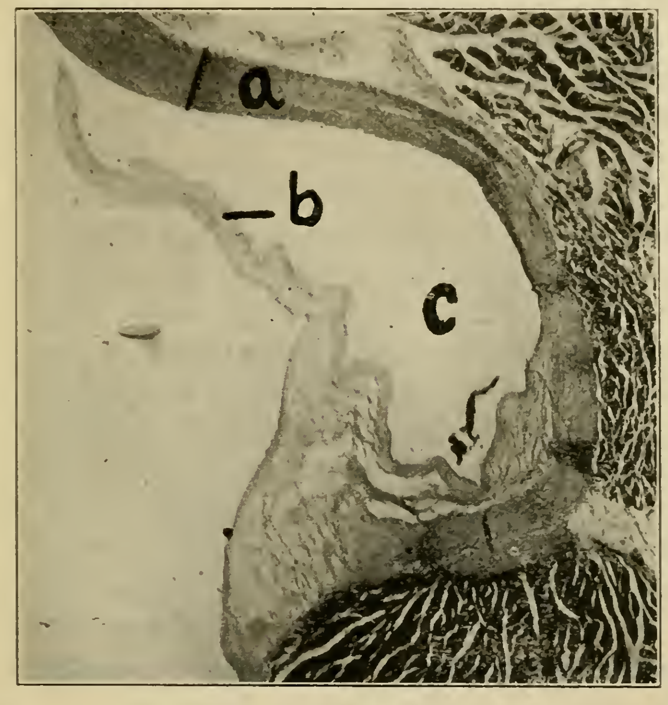


FIG. 120.—SECTION OF THE ROOT OF THE AORTA AND AN AORTIC VALVE. *a*, Aorta; *b*, aortic valve, *c*, sinus of Valsalva. (Photograph. Obj. 32 mm., oc. 5 ×.)

The **atrioventricular bundle,** or **bundle of His,** consists of a bundle of peculiar fibers that connects atria and ventricles. It arises in the interatrial septum and on the right side thereof, near the orifice of the coronary sinus, and adjacent points; it then passes forward between the annulus ovalis and the atrioventricular orifice, the fibers converging to form a *node;* from this node a single bundle is formed that turns down into the atrioventricular septum at the base of the median leaflet of the tricuspid valve; it passes into the *pars mem-*

branacea septi, and at the beginning of the muscular portion of the interventricular septum it divides into two fasciculi, one for each ventricle. These bundles lie just beneath the endocardium, surrounded and insulated by fibrous connective-tissue sheaths. Passing toward the apex of the heart each bundle upon reaching the lower third sends branches to the papillary muscles and there forms a large number of twigs that extend in all directions over the ventricular surface and come into histologic relation with the cardiac muscle fibers. The main bundle is in relation with a *bursa* and the entire bundle is supplied by an artery from the right coronary. Other similar fibers form a network in the atrial wall near the entrance of the superior vena cava. These constitute the *node of Keath and Flack*. Here the cardiac contraction begins.

The muscle fibers, less differentiated than those of the general myocardium are striated but the sarcoplasm predominates. The fibrillæ are few and peripherally placed, forming a circle, or irregular or triangular groups. The volume and size is greater than in the ordinary cardiac fibers. The pigmentation is localized and not prominent. The cell-boundaries cannot be definitely located so that these cells form a *syncytium*. These fibers represent early stages of muscle development from undifferentiated protoplasm. The vagal and sympathetic nerves supply this bundle.

The **myocardium** consists of involuntary striated muscle. In the atria the fibers are arranged in two layers, *inner* and *outer*. The inner layer consists of two sets, one of which loops over each atrium from front to back; the other, *annular* fibers surround the appendages and form rings about the orifices of the veins and the fossa ovalis. In the *outer* layer the fibers run transversely from one atrium to the other predominating upon the ventral surfaces of the atria. In the ventricles the fibers cannot be separated so distinctly into layers. Some run longitudinally, others transversely, while the greatest number have an oblique, circular, or spiral course, forming even a figure eight. Owing to this arrangement distinct lamellæ cannot be formed. Usually incomplete *internal* and *external longitudinal* layers are formed between which are seen the *circular* fibers that form the thickest layer. Besides the latter are found spiral and oblique fibers that are present chiefly in the upper and lower portions of the left ventricle. Most of the layers terminate in the papillary muscles.

A delicate meshwork of areolar tissue is seen between the muscle fibers; this is the *endomysium* and it supports the numerous vessels and muscle fibers. At the endocardial and epicardial surfaces of the myocardium the fibrous tissue is a little more abundant and serves to connect these coats together. These layers of fibrous tissue constitute the *internal* and *external perimysial sheaths*, respectively.

The **epicardium,** or **visceral layer of the pericardium,** consists of a single layer of *endothelial cells* resting upon the *subendothelial* tissue. It differs from the endocardium in possessing no muscle tissue and is separated from the myocardium more or less completely by a thin layer of adipose tissue. The deeper fibers connect it with the external perimysium of the myocardium. It is thickest over the main branches of the coronary vessels where fat is usually found.

The **pericardium** consists of two parts, *serous* and *fibrous*. The *serous pericardium* is a continuation of the epicardium over the great vessels and upon the inner surface of the fibrous portion. The *fibrous* portion is a sack-like organ, consists of dense white fibrous tissue and serves as a protection to the heart. It is attached by its base to the diaphragm and its apex is continuous with the fascia of the neck.

The *blood-vessels* of the heart are branches of the coronary arteries; the capillaries form plexuses parallel to the long axes of the muscle strands and they may even lie in grooves on the strands. The venous capillaries attain a size of 0.25 mm. before continuing as venules. The endocardium is nourished by the blood that flows over it.

The *lymphatics* are superficial and deep. They are present in all of the coats but do not communicate with one another to any great extent. The lymph capillaries are numerous especially in the myocardium and epicardium.

The *nerves* are from both systems and sympathetic ganglia are numerous. The *sensor nerve plexuses* are subendocardial. The fibers end in direct contact with the endothelial cells of the endocardium and chordæ tendineæ. In addition end-plates are also present, especially in the atrial endocardium and in the epicardium.

The *afferent nerves* are derived from plexuses at the intersection of which are found ganglia of various sizes. Individual amyelinated nerve fibers pass to each muscle cell and terminate upon its surface in many fine fibrils that spread over each nucleated segment or cell. Some of the fibrils may terminate in small granules or knobs. The ganglia comprise four to five groups of ganglion cells upon the dorsal walls of the atria in the region of the interatrial septum.

The blood is sent from and returned to the heart by the **vessels.** Of these there are three varieties: (1) **arteries,** or **efferent** vessels; (2) **capillaries,** or **connecting** vessels; (3) **veins,** or **afferent** vessels. The arteries carry oxygenated blood with the exception of the pulmonary arteries; the latter in that one particular resemble veins. Arteries, however, always carry the blood away from the heart, toward the periphery.

1. For convenience of description, the **arteries** or **efferent** vessels are classed as **large, medium** and **small.** The **large** are the **aorta** and **pulmonary artery**; the **medium** the remainder of the named arteries of the body, and the **small,** the unnamed branches that gradually become capillaries. All have the same general structure, consisting of three coats, **tunica intima, tunica media** and **tunica adventitia**; they carry the blood from the heart.

As the medium-sized artery is the type, its description will be considered first and then the differences between it and the others will be pointed out.

Medium-sized Artery.—The tunica intima, or **interna,** consists of three layers, the *endothelial*, *subendothelial* and an *internal elastic lamina.* It is elastic but easily broken in any direction so that it does not strip readily. It is usually corrugated or wrinkled due to the contraction of the artery after death.

The *endothelial cells* are elliptical, or irregular, elongated cells with clear outlines and prominent nucleus and nucleolus. The layer of cytoplasm is usually so thin that the nuclei form a bulge. The cells form a continuous surface and their serrated edges are held together by a small amount of intercellular cement. This is readily outlined by the silver nitrate method. These cells rest upon the subendothelial fibroelastic tissue in which numerous tissue spaces exist. The elastic fibers are delicate and this layer is usually thin.

Limiting this coat is a prominent wavy band (on transverse section of the artery) of elastic tissue, the *internal elastic lamina.* This is usually not solid but shows a number of perforations for which reason it is sometimes called a *fenestrated membrane.* It does not take the ordinary plasmatic stains well and therefore appears as a light band. It stains readily with the elastica stains.

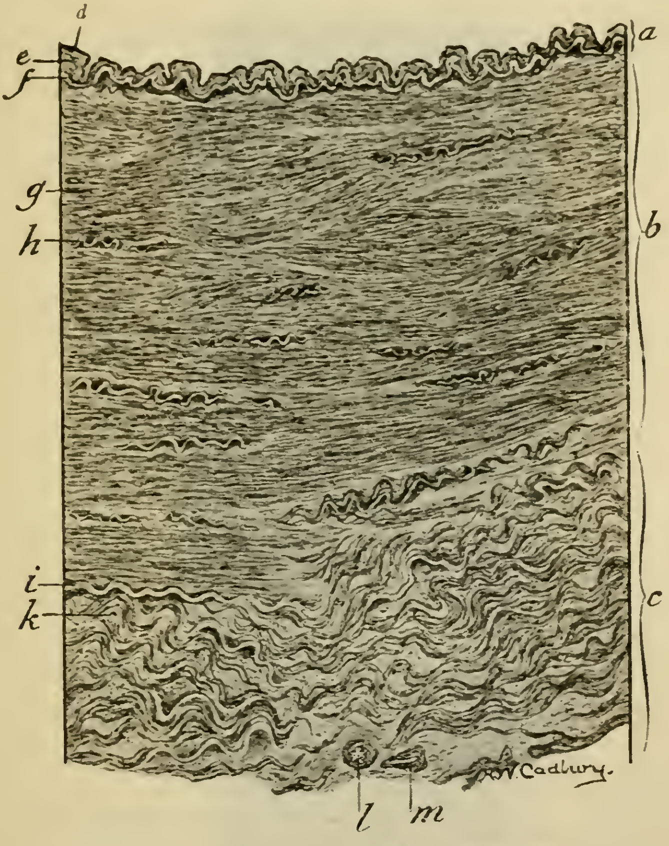


FIG. 121.—CROSS-SECTION OF A MEDIUM-SIZED ARTERY.

a, Intima; *b*, media; *c*, adventitia; *d*, endothelial cells; *e*, subendothelial tissue; *f*, internal elastic lamina; *g*, circular muscle tissue; *h*, elastic fibers; *i*, external elastic lamina; *k*, white fibrous tissue; *l*, arteriole; *m*, venule, vasa vasorum.

The **tunica media** consists chiefly of circularly arranged involuntary nonstriated muscle tissue. The fibers are small and closely packed. At the origins of the branches of the abdominal aorta oblique and even longitudinally arranged smooth muscle may be found. The muscle fibers are held together by a small amount of white fibrous tissue and numerous yellow elastic fibers are present. Some of the latter run transversely and others course obliquely. Often a band of elastic tissue separates the media from the adventitia; this is the *external elastic lamina* but it is not so thick nor so prominent as the internal lamina. Some consider this lamina a part of the adventitia.

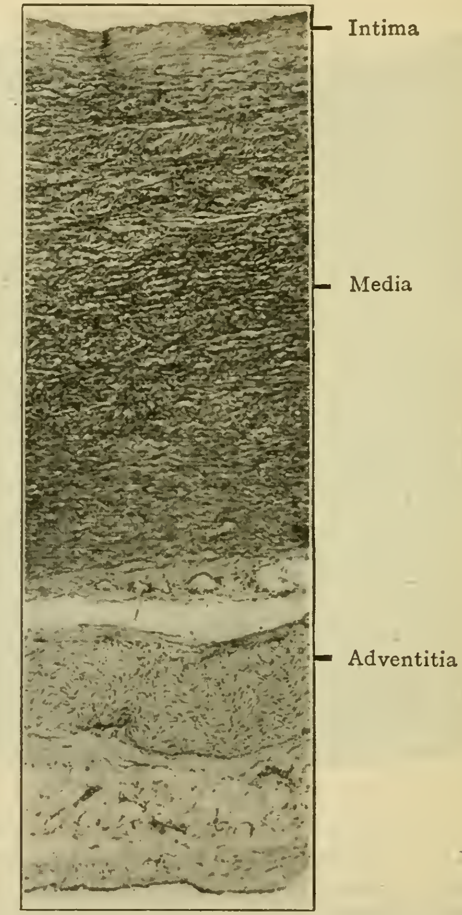


Fig. 122.—Cross-section of the Human Aorta. Hematoxylin and Eosin Stain. (Photograph. Obj. 16 mm., oc. 7.5 ×.)

The media forms a considerable portion of the thickness of the arterial wall and it is usually thicker on one side than the other.

The **tunica adventitia,** or **externa,** is a thick fibro-elastic coat, and protects the vessel from undue dilatation. The elastic tissue is very abundant and consists of coarse fibers that are longitudinally arranged near the media. In some vessels, as renal and splenic arteries, longitudinal muscles fibers are found. It is about one-half or two-thirds the thickness of the media. This coat contains the larger trunks that nourish the vessels, the *vasa vasorum*. The *nervi vasorum* are present also, and form branches that pass to the muscle coat.

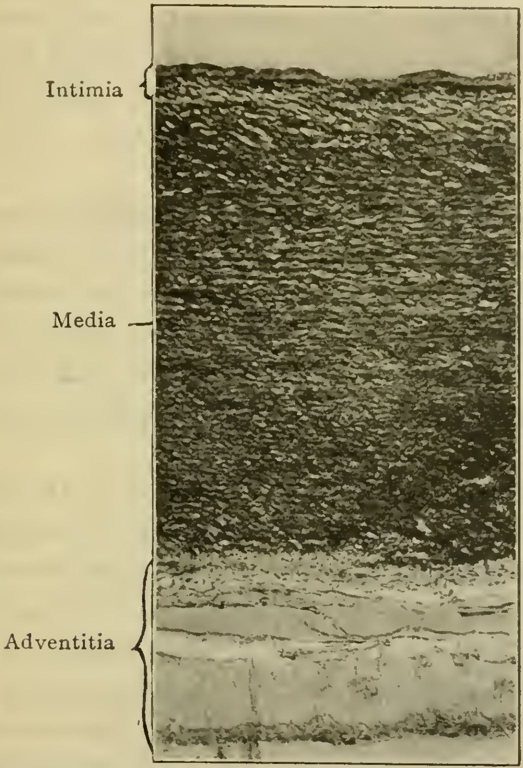


FIG. 123.—CROSS-SECTION OF THE HUMAN AORTA. WEIGERT'S ELASTICA STAIN. (Photograph. Obj. 16 mm., oc. 5 ×.)

The **large arteries** are mainly elastic tubes. The *intima* is not so distinct and gradually fades into the media. The *endothelial cells* are shorter. In the aorta an *internal elastic lamina* is not present but is often found in the common iliac arteries where it may be double. The elastic fibers usually fuse to form the fenestrated membrane of Henle. Although the *media* is very thick the muscle tissue is comparatively scant and the *elastic tissue predominates*. The muscle fibers, which are often forked, are scattered among the elastic fibers so that this coat does not stain as deeply as the corresponding coat of the medium-sized arteries. This coat is very elastic but not contractile. The same structure prevails in the large branches of the aorta. The *adventitia* is usually thin but otherwise resembles that of other arteries.

In **small arteries** the muscle tissue predominates and these are contractile tubes. The *intima* is thinner but the elastic lamina is very prominent and thick. The *media* is proportionately thicker than in other arteries and consists entirely of smooth muscle-tissue circularly arranged. Elastic tissue is practically absent although at times a thin external elastic lamina may be seen. The *adventitia* is thin.

From birth to old age the intima increases rapidly from 6 microns to 19 microns in thickness and the media up to 650 microns, while the adventitia decreases. As old age advances the vessels lose their elasticity through the conversion of the elastic tissue into inelastic *elacin*. As the continued blood-pressure would tend to increase the caliber this condition is overcome by the special thickening of the intima.

The difference in structure may be explained by the difference in function of the arteries. The large arteries are practically elastic tubes, the main tissue being elastic. These vessels must be able to suddenly increase their capacity and return to the normal caliber without injury but they must not reduce their caliber to any appreciable extent. When the heart contracts a large volume of blood is suddenly forced into the large arteries and they dilate to accommodate it. Through the natural recoil of the stretched elastic tissue and the removal of the resistance ahead (the flow of the blood into the smaller arteries) the blood in the large arteries is gradually forced onward and the vessels return to their normal caliber. They must not decrease this caliber for if that were to occur it would increase the resistance to the blood entering from the heart and cause this organ to hypertrophy to overcome this increased resistance.

The medium-sized arteries are mainly contractile vessels and yet they have sufficient elastic tissue in their walls to permit of some dilatation. Their normal caliber is sufficient for the ordinary blood-supply and if more blood is required they can relax their muscle tissue and even be stretched some without injury. If the amount of blood be too great these vessels can contract and cut down the amount somewhat.

The small arteries and arterioles have no elastic tissue except an elastic lamina. These vessels are the ones that mainly control the supply of blood to a part and it is upon these that many drugs given for that action have their effect. These are essentially only contractile tubes and are for the purpose of cutting down the amount of blood and to prevent congestion. If that amount is not sufficient then by the relaxation of the muscle tissue in their walls the vessel increases its caliber and so permits of more blood. The caliber of these vessels in the living condition is somewhat smaller than in the dead because under normal conditions all of the smooth muscles of the body are slightly contracted all of the time and this is called *tonic contraction* (due to adrenalin probably). If this tonic contraction be withdrawn then the vessels dilate somewhat through the relaxation of the muscle.

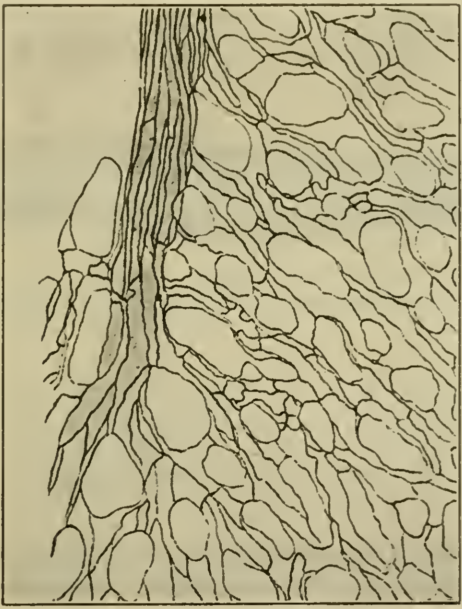


FIG. 124.—SMALL ARTERIOLE FORMING CAPILLARIES.
The irregular outlines of the endothelial cells are shown. (*From Schäfer after Mann.*)

Variations in the structure of some of the arteries are to be found. The roots of the aorta and pulmonary artery usually contain a considerable amount of cardiac muscle tissue. The arch of the aorta may contain some smooth muscle tissue, longitudinally arranged, in all three coats. Some of the larger branches may have spirally directed muscles, especially those vessels that are bent. The arteries of the brain and its coverings are all thin-walled and the only elastic tissue present is in the lamina.

As the vessels become reduced, the intima is the first to suffer; the subendothelial tissue disappears, and the endothelial cells are seen to rest upon the elastic lamina. The media becomes attenuated so that only a single layer of muscle fibers is seen. This soon becomes reduced to a few stray fibers. The adventitia becomes greatly reduced and is represented by a few bundles of fibrous tissue. This is practically the **precapillary vessel**. It is succeeded by the **capillary.**

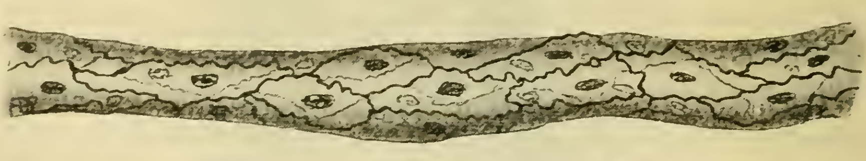


FIG. 125.—CAPILLARY (FROG'S MESENTERY) TREATED WITH SILVER NITRATE TO OUTLINE THE ENDOTHELIAL CELLS. (*After Ranvier.*)

2. The **capillaries** or **connecting** vessels are merely delicate tubes consisting of a single layer of endothelial cells placed end to end, and held together by intercellular cement. These are readily outlined with silver nitrate. These cells are not so firmly united but that the leukocytes can force their way between them (*diapedesis*). These openings thus formed are the stigmata and they are not permanent. The endothelium is held by some to be phagocytic. They are the smallest vessels, and anastomose freely to form loose or dense plexuses. At times they are very irregular, possessing dilatations. They are practically very thin animal membranes, and through their walls the liquid portion of the blood and the ameboid white blood cells have no difficulty in passing into the surrounding tissues. Small capillaries average 5 to 7 microns in

diameter, 500 microns in length, and cross-sections show that they are encircled by two endothelial cells. Large capillaries average 8 to 13 microns and are encircled by three to four endothelial cells. Stöhr claims that capillaries can contract as nerve endings are found in the cells.

Capillaries are found in practically all tissues except epithelium and cartilage. In the organs in general the capillaries are not in direct contact with the functionating cells but are separated by a space into which the lymph passes and bathes the cells. The meshes are long and narrow in tendons, muscles and nerves. In mucous membranes and the skin the capillaries form loops. In the lungs, glands and fat the meshes are close.

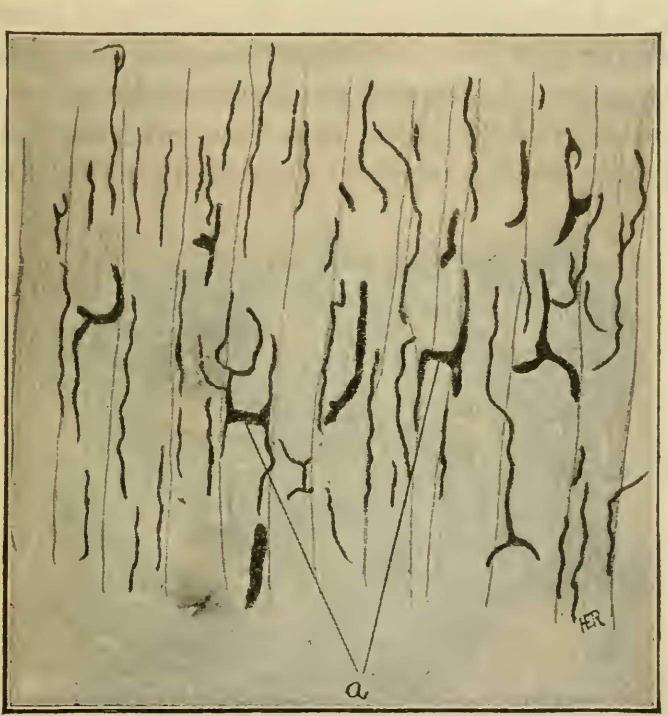


Fig. 126.—Longitudinal Section of Voluntary Muscle of a Guinea-pig, Injected, Showing the Course of the Capillaries.
a, Ampullæ. (*Radasch, Reference Handbook of the Medical Sciences.*)

In certain tissues and organs the capillaries are peculiarly modified. In the skeletal muscles the capillaries run parallel to the course of the fibers and are connected to one another by cross-branches that dilate readily. These are the *ampullæ* and during the contraction of the muscle are dilated with blood from the longitudinal vessels, and so take the strain from these. In the liver, adrenal, spleen and carotid gland the endothelium of the capillaries is in direct contact with the functionating epithelium or parenchyma of the gland. These capillaries are called *sinusoids* (Minot) and the nutritional relation is of the closest. No spaces exist between the vessels and the epithelium and the nutritional elements pass directly into the cells and any internal secretion may pass directly into the capillaries. In parts of the cortex of the kidney arterioles break up into a series of capillary tufts from which the blood is again collected by the efferent arteriole; the tuft is a series of capillaries. interposed between two arterioles and is called a *retia mirabilia.* In the penis and clitoris no regular capillaries exist in the corpora cavernosa. Here the arterioles pass the blood into large dilated cavernous spaces lined with endothelial cells and these are *sinuses.* In exposed regions, nose, ears, toes, kidneys and membranes of the nerve system, direct communications between the arteries and veins exist. These are *anastomoses* and are not to be confused with the anastomoses that normally occur between arteries which form the anastomotic circulations of the extremities and certain organs.

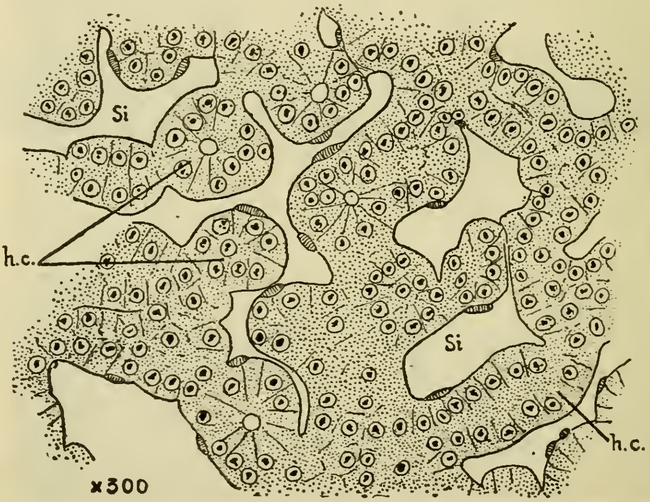


FIG. 127.—SINUSOIDS (SI) IN THE LIVER OF A CHICK EMBRYO OF ELEVEN DAYS. (*Lewis and Stöhr after Minot.*)

h.c., Cords and tubules of hepatic cells.

The **veins** or **afferent vessels** have the same general structure as arteries but the coats are thinner. These vessels collapse readily when cut but they are nevertheless strong. They carry the blood toward the heart, are more numerous and larger than the arteries and anastomose more freely. The **precapillary venules** are mere tubes of endothelium supported by a delicate network of fibro-elastic tissue.

The **coats** are *tunica intima, tunica media* and *tunica adventitia.*

The *tunica intima* is usually tougher than in the arteries and may be stripped more readily. The *endothelial cells* are short and broad; the *subendothelial tissue* is not well developed and the *internal elastic lamina* is not marked as the elastic tissue tends to form a sort of network and not a membrane. In some veins smooth muscle tissue longitudinally arranged is found in the intima.

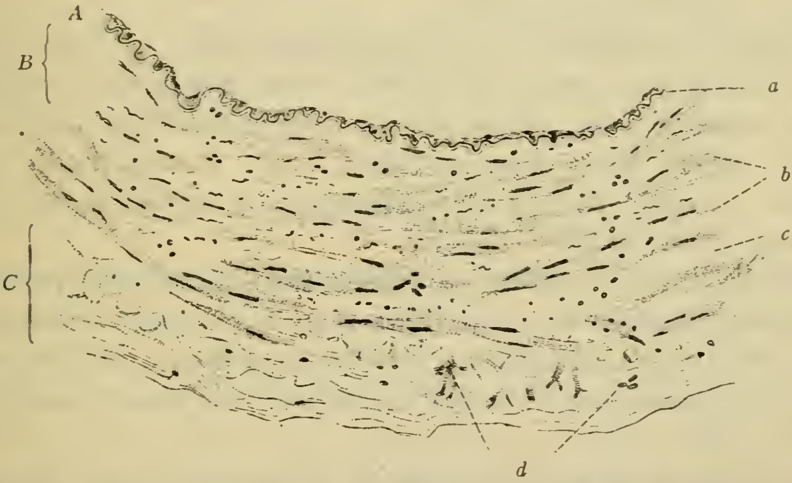


FIG. 128.—PORTION OF A CROSS-SECTION OF A HUMAN VEIN.

A, Intima; *B*, Media; *C*, Adventitia—*a*, Internal elastic lamina; *b*, smooth muscle fibers; *c*, white fibrous connective tissue; *d*, smooth muscle fibers in the adventitia. (*Stöhr's Histology.*)

At intervals this coat is thrown into folds called *valves*. These are duplications of the intima. Each valve is a semilunar fold of intima having a central mass of white fibrous tissue that gives it added strength. These are usually attached in pairs and opposite the points of attachment the vein is dilated forming *pouches* or *sinuses.* When filled with blood these pouches produce a marked bulge. The valves prevent a reflux of the blood but present no obstruction to the onflowing blood. Valves occur in all of the veins except the venæ cavæ, portal, pulmonary, hepatic, innominate, common iliacs, mesenteric, splenic, uterine, ovarian, cranial cavity, vertebral canal, cancellous bone and the renal veins.

The *tunica media* contains a relatively small amount of smooth muscle tissue that is circularly arranged. The bulk of this coat consists of fibroelastic tissue. In the veins of brain and bones and in the thoracic part of the inferior vena cava muscle tissue is wanting. In the crural, mesenteric and iliac veins some longitudinal muscle tissue is found near the intima.

The *tunica adventitia* is the most prominent coat. In some vessels as the abdominal part of the inferior vena cava, renal, spermatic, azygos, external iliac, splenic, hepatic and portal veins longitudinal smooth muscle tissue may be found in it. It consists of coarse bundles of white fibrous and yellow elastic tissues and contains the vessels and nerves of the vein.

Veins are merely conducting vessels and cannot assist in forcing the blood along as arteries do. They must be capable of considerable distention and no contraction, hence the presence of fibro-elastic tissue in preponderance in the media and the small quantity of muscle tissue.

The *blood-vessels* are nourished by the *vasa vasorum.* These lie in the adventitia and from them small branches pass chiefly to the media, mainly for the muscle tissue. The intima has very few capillaries as it is nourished by the blood that flows over it.

Lymphatics are numerous. Blood-vessels are often the centers of extensive lymph channels that lie in the adventitia, and constitute the perivascular lymphatics.

The *nerves* are chiefly sympathetic and are distributed to the media and adventitia. These are the *nervi vasorum* and they form plexuses around the vessels. They are *motor* and *sensor.* The motor fibers utimately terminate in the muscle tissue. The *sensor* fibers are connected with end-plates in the intima. Pacinian bodies are also found in the adventitia.

TABLE OF COMPARISON OF ARTERIES AND VEINS

Character	Arteries	Veins
Coats.	Three.	Three.
Size.	Thick.	Thin.
Intima.	Elastic lamina prominent.	Not prominent; may be absent.
Media.	Mainly smooth muscle.	Little muscle, mainly white fibrous tissue.
When empty.	Do not collapse readily.	Collapse readily.
Valves.	Absent.	Usually present.
Course of the blood.	From the heart.	Toward the heart.
Character of the blood.	Oxygenated (with exception of that in the pulmonary artery).	Deoxygenated (with exception of that in the pulmonary veins).

BLOOD

Blood and **lymph** are the only liquid connective tissues. Blood is of an alkaline reaction, has a peculiar and characteristic odor due to a volatile fatty acid in combination with an alkaline base. Its specific gravity (1.051 to 1.056) is diminished by liquid foods and increased by solid foods. The temperature averages 38°C. This varies as follows: Inferior vena cava 36.7°C. (98.2°F.); hepatic vein 39.7°C. (103.4°F.). It is composed of *cellular elements*, the *corpuscles*, and the *intercellular substance*, or *liquor sanguinis*. The quantity of blood seems to vary at different ages. In the infant it represents one-nineteenth of the body weight and in the adult one-thirteenth, although later investigation seems to give one-nineteenth also for the adult.

The **cellular elements** are of three varieties, the **red cells, white cells** and **platelets.** These are said to represent 328 parts and the liquor sanguinis 672 parts.

The **red cells,** or **erythrocytes,** are *nonnucleated, bell-shaped* elements varying from 5 to 9 microns and averaging 7 to 8.5 microns in diameter and 1.9 to 2.0 microns in thickness. The bell-shape is not seen unless the necessary precautions are exercised, that is to fix the blood before it becomes exposed to the air (see **Blood Technic,** p. 44). These cells have been studied under various conditions by Weidenreich and Lewis and the author has found that they are to be readily studied in fetal tissues. Upon exposure to air these bell-shaped cells collapse and this accounts for the usual description as that of a biconcave disc. Schäfer and others maintain that the red cells are normally biconcave. When fresh normal blood is examined under the microscope these cells form rouleaux, and this is said to be due to the cells fitting into one another. When exposed to air these cells collapse and resemble rolls of coins on edge.

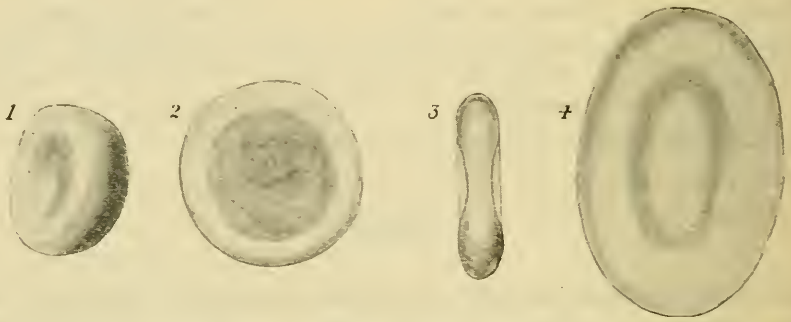


Fig. 129.—Red Blood Cells.

Red blood-cells. 1, Bell-shaped red blood-cell of man; 2, surface view of collapsed bell-shaped cell; 3, side view of 2; 4, surface view of red blood cell of the frog.

Under the microscope each cell is pale straw-colored or greenish. It consists of a framework, the *stroma*, that contains an organic iron compound that carries the oxygen; this is the *hemoglobin*. The presence of a cell membrane is still a matter of dispute.

Weidenreich states that the red cells are surrounded by a structureless and colorless membrane enclosing a colored semi-fluid mass that consists chemically of proteins, lecithin, cholesterin, inorganic salts and hemoglobin. A *stroma* does not exist in the adult stage of the cells. The *envelop* will stain with magenta and methyl violet. It is elastic and the cells can change their form and regain their shape.

Some cells average from 5.5 to 7.5 microns, and are called *microcytes*, while those over 8.5 microns are *macrocytes*. Bethe found the various red cells in the following proportions: 6.92 microns, 42 per cent.; 7.26 microns, 28 per cent.; 8.58 microns, 16 per cent.; 6.6 microns, 8 per cent.; 9.24 microns, 6 per cent.

In normal blood, the cells tend to form rolls, or *rouleaux*. Under the same condition, 5,000,000 corpuscles are found, per cubic mm., in the male, and about 4,500,000 in the female.

Nucleated red blood-cells, or *erythroblasts* are found in the fetus, in red bone-marrow and in the spleen (at times). The cells of average size are called *normoblasts,* the smaller ones *microblasts* and the larger ones *macroblasts*.

In fishes, amphibians, reptiles and birds the red cells are nucleated and usually oval in form. In mammals they are nonnucleated and circular in form, with the exception of the camel family; in these animals the cells are oval in shape. In the frog the red cells are very large, oval, biconcave nucleated cells and are far larger than the same cells in man, measuring about 24 microns in length and 14.5 microns in width.

The size of the red cell is by no means proportionate to that of the animal. The musk deer possesses one of the smallest (2.4 microns); in proteus the red cell measures 62.5 microns by 34.5 microns, while in amphiuma the red cells are about one-third larger. That of the elephant is but 9.2 microns in diameter and beside it stands that of the humming bird, with a diameter of nearly 9.4 microns.

The number of red cells is affected by altitude; at 314 meters above sea level the number is 5,322,000; at 700 meters 5,900,000; at 1800 meters 7,000,000; at 4392 meters 8,000,000. This increase is affected during two or three weeks and upon return to sea level the number gradually drops to 5,000,000 again (Köppe). There is apparently no difference of number in the different races.

The red cells are more numerous in carnivorous than in herbivorous animals, while in birds they are larger in size. In the amphibians, where the size is great, the number is small. In the dog the red cells measure about 7 microns in diameter; in the sheep 5 microns; in the goat 4 microns; in birds 8.5 to 14.5 microns.

According to Malassez and Hayem, each cu. mm. of goat's blood contains 18 to 19 millions of red cells; birds 2 to 3 millions; reptiles 0.5 to 1.6 millions; frogs 400,000; proteus 36,000; bony fishes 1 to 2 millions; torpedo 140,000.

The **white blood cells,** or **leukocytes** are large pale cells readily distinguised from the above. They consist of about 90 per cent. water and 10 per cent. of solids (proteins, lecithin, glycogen, fat and phosphorus). About 5000 to 8000 are found in each cubic millimeter of blood; there is a physiologic increase at certain times, after meals, especially those rich in protein material. Fasting reduces the number and in total abstinence of food the number may fall to 1000 per cu. mm. At birth they number 17,000 to 20,000 per cu. mm. while in the adult the number is as above, or 1 to every 700 red cells. The proportion in the splenic aertery is 1 to 2260 red cells and in the splenic vein 1 to 60 red cells; in the portal vein the proportion is 1 to 740 and in the hepatic vein 1 to 170 red cells. Some of the leukocytes are actively ameboid and phagocytic.

The *cytoplasm* of the leukocytes is reticular even in the living cells; in addition granules of various types may be present. The *nucleus* varies from small to large and its stain reaction is not the same in all leukocytes. Some are multinuclear. A *centrosome* and *attraction sphere* are usually to be found near the nucleus.

They are classified as follows:

1. **Lymphocytes** (small lymphocytes).
2. **Hyalin cells** (large lymphocytes).
3. **Polymorphonuclear leukocytes,** or **finely granular oxyphils** (*Formerly neutrophil*).
4. **Coarsely granular oxyphils** (*Formerly acidophil*).
5. **Finely granular basophils.**
6. **Coarsely granular basophils.**

1. The **lymphocytes,** or **microleukocytes,** are the smallest of the white cells, average 4.5 to 7.5 microms in diameter and are the first to form. Each consists of a large darkly staining nucleus surrounded by a narrow rim of faintly staining cytoplasm that may be basophilic in reaction. The large nucleus is nearly spherical in form and the chromatin is prominent. This variety is formed mainly in the lymphoid tissues and organs and some arise in the red bone-marrow. This variety is both *ameboid* and *phagocytic* and constitutes about 20 to 25 per cent. of the white cells.

2. The **hyalin cell**, or **macrolymphocyte**, is the largest white cell and averages from 11 to 15 microns in diameter. It is said that they are derived from the lymphocytes which they resemble. Both nucleus and cytoplasm stain but faintly, hence the name. In the cytoplasm some basophilic granules are occasionally seen. The nucleus is large, usually hazy in appearance and often kidney-shaped. This cell is *actively ameboid* and *phagocytic*. They are found in lymphoid tissues and organs and some are formed in the red bone-marrow. They represent from 2 to 4 per cent. of the white cells.

3. The **finely granular eosinophils**, or **finely granular acidophils** (*polymorphonuclear neutrophils*) are the most numerous of the white cells and average from 7.5 to 10 microns in diameter. There are said to be several stages of this cell, the younger showing a centrosome and nucleus that contains little chromatin and fewer modifications of nuclear shapes, and older ones that have a dense chromatic network and more varieties of nuclear shapes. The latter may be U, V, W, etc., and may even be divided into a number of segments. The younger cells are said to be capable of reproducing to a slight extent and the older ones not at all. The cytoplasm contain a large number of fine granules that usually take the plasmatic stains quite deeply. These granules were at one time thought to be neutrophilic and the cells were called neutrophils. These cells are increased in number after a meal and are formed in the red bone marrow. They are *actively ameboid* and *phagocytic* and represent 60 to 70 per cent. of all of the leukocytes. They are the active infection fighters of the body and are the chief cells seen in such areas.

4. The **coarsely granular eosinophil**, or **eosinophil** is 7 to 10 microns in diameter. The cytoplasm contains a few large granules that take the plasmatic stains very deeply. Ehrlich suggests that these granules may be zymogen granules. The deeply staining nucleus may be horseshoe-shaped or lobulated. The younger cells contain a centrosome and are capable of division but the older ones are not. They are formed in the red bone-marrow and are *actively ameboid* but *not phagocytic*. They represent from 1 to 4 per cent. of the white cells in the child but rarely run over 2 per cent. in the adult.

5. The **finely granular basophil** resembles group 3 except that the granules take a basic stain. These are formed in the red bone

marrow and are present to the extent of 0.1 to 1 per cent., but are usually under 0.25 per cent.

6. The **coarsely granular basophil** is said to be absent from normal blood. They are relatively large cells and are also called *mast cells*.

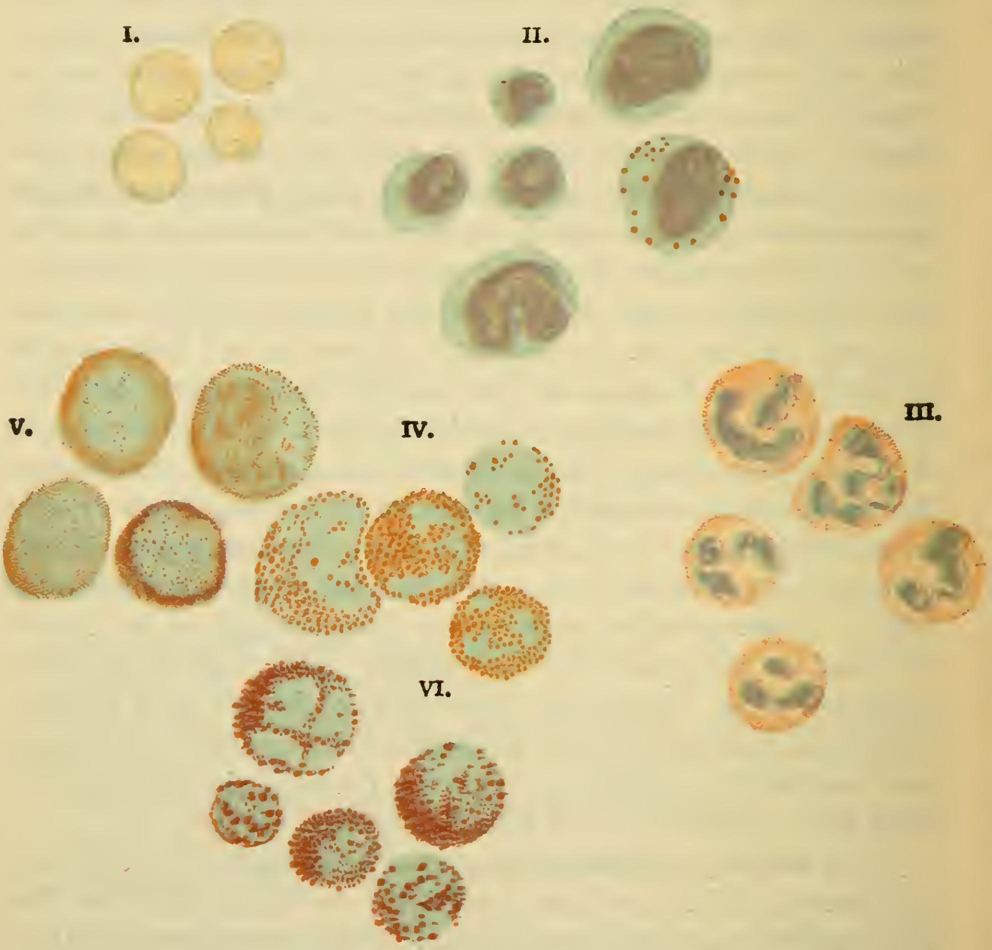


FIG. 130.—THE BLOOD CORPUSCLES. (WRIGHT'S STAIN.) (*E. F. Faber, from Da Costa's Clinical Hæmatology.*)

I, Red corpuscles. II, Lymphocytes and large mononuclear leucocytes. III, Neutrophiles. IV, Eosinophiles. V, Myelocytes (not found in normal blood). VI, Mast cells.

The cytoplasm contains a number of large coarse granules that respond well to the basic stains. The nucleus stain readily and varies in shape. They are said to be present to the extent of 0.5 per cent. Some consider these cells are eosinophils in a state of degeneration; the granules represent fragments of the nucleus and products that are the result of mucoid degeneration of the cytoplasm. Maximow considers them special leukocytes. They are formed in the red bone-marrow and are also found in areolar tissue where they probably end their existence. In certain diseases they increase in number in the marrow and spleen and are found in the blood in greater numbers.

The *leukocytes* are *general scavengers* as they remove foreign bodies, bacteria and disintegrating tissues. This process is called *phagocytosis.* In their dissolution they contribute to the blood plasma certain proteins that assist in the coagulation of the blood.

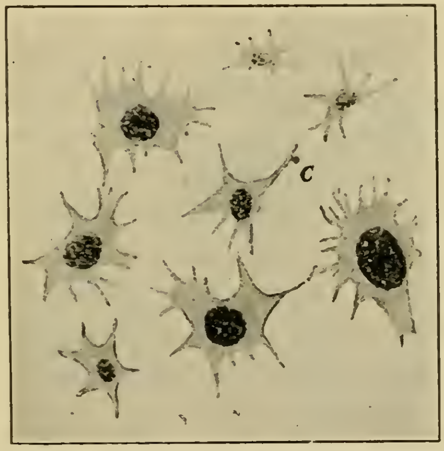


FIG. 131.—BLOOD PLATELETS SHOWING AMEBOID CONDITION AND CHROMIDIA. (*After Kopsch.*)

Some leukocytes are lost in the alimentary tract and some are destroyed by the phagocytes of the spleen, hemolymph nodes and even in lymph nodes.

The **blood platelets,** or **thrombocytes** are small, colorless, oval or circular discs. These are capable of *ameboid movements* and measure from 1 to 3.5 microns in diameter. The cytoplasm is homogeneous or finely granular. Each possesses a chromatin mass (*chromidium*) that apparently represents a nucleus. In drawn blood these elements collect in groups. They stain with basic dyes, especially methyl violet. They number 200,000 to 300,000 per cu. mm. They are formed in red bone marrow and are said to be derived from the myeloplaxes or megakaryocytes, as broken off fragments of their pseudopodia. They are readily found in blood fixed in a 1 per cent. solution of osmic acid.

When these cells come in contact with a foreign body they rapidly throw out processes and adhere to it. In this way they form a plug and assist in stopping hemorrhages, forming a *white clot*, or *thrombus*. They are supposed to contain *prothrombin* which becomes converted into *thrombin or fibrin ferment*. In certain diseases these elements are increased in number while in others they are decreased. According to Helber blood platelets are not found in the blood of frogs or birds.

The **intercellular substance**, or **liquor sanguinis**, contains the salts of the blood. Its density is such that the cells retain their normal shape. It consists of 90 per cent. water and 10 per cent. of proteins, fats, sugar, inorganic salts, urea, cholesterin, lecithin, etc. It contains not only nutritious substances but waste products and the fibrinogen in solution. If, however, solutions are added that differ in density, the action upon the cells is characteristic.

Upon the addition of strong (*hypertonic*) *salt solution*, the cells become irregular in outline, and are *crenated*. If *water* or salt solutions under 0.5 per cent. (*hypotonic*) be added, it dissolves the hemoglobin, and the cells *swell* and become spherical. These are *blood shadows*. When these burst the particles constitute the *blood dust* or *hemokonia* of Mueller.

The action of *acetic acid* is important. The addition of a 0.3 per cent. solution *decolorizes* the red cells and renders the white cells *more distinct*. This is made use of in **hematology** for the purpose of counting the white cells, in a fresh condition.

An important property of blood is that of *clotting*, or *coagulation*. The *fibrinogen* is precipitated as fibrin and this entangles the cells. As the fibrin contracts the liquid portion of the blood and the salts are separated as a yellowish fluid which is the *serum*. This contains no fibrinogen. The *clot* contains the fibrin and the entangled cells. The precipitation of the fibrinogen is due to some agent, called *thrombin*, that is formed by the leukocytes in their decomposition or dissolution and by the thrombocytes. Coagulation of the blood may be hindered by the addition of certain salts as magnesium sulphate and potassium oxalate, or by cold. Clotting is hastened by stirring, the addition of foreign bodies or by keeping the blood at a temperature of 38° to 50°C. The lack of certain substances in the blood leads to difficulty of coagulation and such persons are known as *bleeders;* the condition is known as *hemophilia.*

Hemoglobin is an organic iron compound of a globulin and as it exists in the blood it cannot readily be studied. In the lungs the oxygen forms an unstable compound called *oxyhemoglobin* and in the tissue spaces the affinity for or need of oxygen is so great that it is readily removed from the hemoglobin. The bright red color of blood of the arteries is due to this compound. It is probably in solution in the cytoplasm of the erythrocytes from which it may readily be removed by ether or it can be easily converted into a crystallin form.

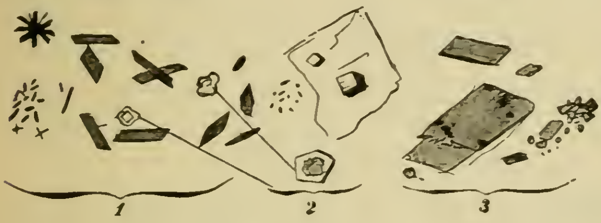


FIG. 132.

1, Hemin crystals of man (× 560); 2, crystals of common salt; 3, hematoidin crystals of man. (*Stöhr's Histology.*)

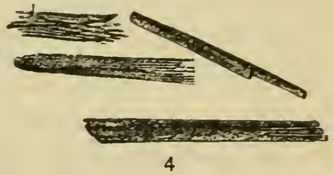


FIG. 133.—HEMOGLOBIN CRYSTALS OF A DOG (× 100); a crystal separating into fibers. (*Stöhr's Histology.*)

Hemoglobin crystals will be formed if a drop of defibrinated blood be mixed with a drop of Canada balsam, or clove oil, and covered with a cover-glass. They are large, red, rhombohedral crystals or elongated prisms in man.

Hemin crystals may be prepared by adding a small crystal of salt and two drops of glacial acetic acid to a little dried blood, and heating until the mixture boils. During this process it should be covered. When cool, small brownish crystals (*hemin chlorid*) will be found. These may be single or grouped in the form of rosettes, and are known as *Teichmann's crystals.* As these crystals will form as readily in old dried specimens of blood as in fresh specimens this test is of importance medico-legally.

Hemosiderin is a decomposition derivative of hemoglobin containing iron. These light brown granules are found in the bone-marrow and spleen and even in phagocytes. Iron in the tissues and iron pigments are no doubt derived from the same source.

Hemotoidin is another derivative of hemoglobin but it contains no iron. It can be prepared as needle-like crystals of a yellowish color. It is found in the spleen, derived from the disintegrating red cells; from the spleen it is carried to the liver where it is utilized as bilirubin.

Among other blood-making organs are placed the **coccygeal** and **intercarotid glands** and **hemolymph nodes.**

Luschka's gland (2.5 mm. in diameter), is found in front of the tip of the coccyx, and is connected with the middle sacral artery. It is surrounded by a fibrous sheath, which sends in septa that divide the organ irregularly into *areas*, or *compartments*. The latter contains groups of polyhedral cells surrounded by dense plexuses of capillaries of the sinusoidal type. The cells consist of a finely granular cytoplasm and a palely staining nucleus. Many of the cells contain a yellowish pigment that gives the chromaffin reaction. Amyelinated nerve fibers are numerous.

The **intercarotid gland** is found at the bifurcation of the common carotid artery, and its structure is similar to that of Luschka's gland.

Hemolymph (Hemal) Nodes.—These organs vary in size from a pin head to a large bean and are found in abundance in the retroperitoneal and cervical regions and less numerous elsewhere. Each is surrounded by a capsule of white fibrous and yellow elastic tissues, containing a little smooth muscle tissue; trabeculæ pass in and form the framework of the organ. In the framework are found *red* and *white* blood-cells. Of the latter, the lymphocytes are the more numerous; besides these hyalin, finely granular oxyphils and basophils are found in varying numbers. Megakaryocytes are also found here. In addition, mononuclear phagocytes that contain pigment and disintegrating red cells are seen. Beneath the capsule and following the trabeculæ to the hilus are seen sinuses, often very large, that do not contain lymph but blood.

These organs usually possess no lymphatics. The blood-vessels enter at the hilus and form capillaries within the organ; these capillaries communicate with the blood sinuses. The large veins are in the trabeculæ and begin in thin-walled lacunæ that possess perforated walls, by means of which they communicate with the blood sinuses.

Certain atypic organs possess lymphatics. Some of these structures resemble the spleen in structure, others the marrow and still others ordinary lymph nodes.

Nerves are present and probably pass to the smooth muscle tissue.

Parasympathetics, or Aortic Bodies.—These are two to four brownish bodies found in the neighborhood of the inferior mesenteric artery and closely related with the aortic sympathetic plexus. Each is surrounded by a capsule of white fibrous connective tissue that sends in trabeculæ that form the framework of the organ. In the meshes of this framework are found the epithelium which consists of groups of polygonal or cuboidal cells closely packed and of the chromaffin type resembling the cells of the medulla of the adrenal. These structures are found only in childhood and are supposed to be accessory in function to the adrenals.

The *blood-vessels* derived from the aorta, or inferior mesenteric artery, follow the trabeculæ and form a rich capillary plexus around the epithelial cell-groups.

The *nerves* are from the sympathetics and their relation and arrangement are similar to the nerves of the medulla of the adrenal.

HEMAPOIESIS

In the adult the formation of red blood-cells is carried on chiefly by the red bone-marrow; the white blood-cells are formed in the lymphatic tissues and organs and to some extent in the red bone-marrow. In the fetal condition blood-cells are made in a number of places; the yolk-sac is the seat of origin of the first blood-cells; then the somatic mesenchyme and primitive endothelium of the vessels; later the spleen, liver, developing lymphatic organs and the bone-marrow.

Two theories are given as to the origin of the red and white cells; the *monophyletic theory* is that all the cells have a common ancestor, the *hemoblast*, or *hemogonium*; the *polyphyletic theory* is that the red cells have one ancestor and the white cells a different original mother cell. Later investigation seems to indicate that the monophyletic theory is the right one.

In the development and differentiation of these cells the primitive mother cell divides into two daughter cells; one of these cells continues its function as a mother cell and the other is an hemoblast. The hemoblasts are probably carried by the blood-stream to the organs that are to serve an hemapoietic function, where they proliferate. In certain organs they persist throughout life but in those that have only a temporary function of this nature they ultimately disappear therefrom when that function ceases.

According to Maximow the *nucleated red cells* are called *erythrocytes* and the *non-nucleated cells, erythroplastids*. According to him the erythrocytes are of two kinds; the *primitive form* that does not last long and soon disappears and the *definite form* that consists of cells a little smaller than the preceding and that persist and that give rise to all of the red cells.

When the hemoblast divides, one of the daughter cells continues the function of the mother cell and the other undergoes mitosis. One of its daughter cells is the *primitive erythrocyte* and the other is called the *primitive lymphocyte*.

The *primitive erythrocyte* is about 11 microns in diameter and continues to divide for a while but dies out in early embryological stages.

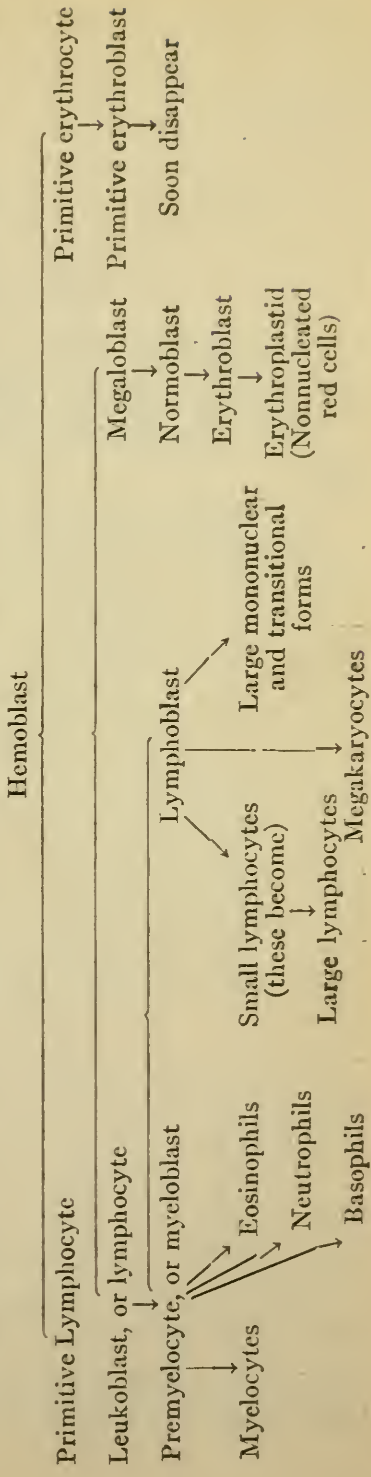
The *primitive leukocyte* is about 9.5 microns in diameter and the cytoplasm contains some basophilic granules. Each divides and one of the daughter cells is the *megaloblast*, the ancestor of the continued red cells, and the other is the *lymphocyte*, the ancestor of the various leukocytes.

The *megaloblast* is about 8 microns in diameter and the cytoplasm contains only a small amount of hemoglobin; the large vesicular nucleus contains only a small amount of chromatin. This is the *ichthyoid stage of Minot*. The daughter cells of the megaloblasts are called normoblasts. These cells are somewhat smaller than their mother cell, the hemoglobin is greater in quantity and the nucleus strains more deeply, due to a greater quantity of chromatin being present. This is the *sauroid stage of Minot*. The daughter cells of the normoblasts are called *erythroblasts*. These cells contain more hemoglobin than their mother cells (normoblasts) and the nucleus is smaller and denser. By a loss of its nucleus the erythroblast becomes the *erythroplastid*. According to some investigators the nucleus is absorbed (*karyolysis*); according to others it is extruded in mass or in fragments (*karyorrhexis*); in the pig the nonnucleated red cells are derived from the erythroblasts by a process of budding, the bud containing no nucleus.

The *lymphocyte*, the other daughter cells of the primitive lymphocyte, is the ancestor of the white blood-cells. One of its daughter cells is called a *lymphocyte* and the other a *leukoblast*. The *lymphocyte* represents the large lymphocyte of the blood and is apparently only a slightly modified original lymphocyte. When these cells divide the small daughter cells are the *small lymphocytes* of the blood; as these grow they become the *large lymphocytes*. From the lymphocytes *megakaryocytes* are also differentiated. These giant cells are 14 to 20 microns in diameter, multinuclear and give rise to the platelets.

The *leukoblast* gives rise to daughter cells which by differentiation become the *myelocytes* and the *granular* and *neutrophilic leukocytes*.

The accompanying diagram will show the derivatives of the hemoblasts.


Hemoblast
Primitive erythrocyte
Primitive erythroblast
Soon disappear
Primitive Lymphocyte
Megaloblast
Normoblast
Erythroblast
Erythroplastid (Nonnucleated red cells)
Leukoblast, or lymphocyte
Lymphoblast
Large mononuclear and transitional forms
Small lymphocytes (these become)
Large lymphocytes
Megakaryocytes
Premyelocyte, or myeloblast
Myelocytes
Eosinophils
Neutrophils
Basophils

CHAPTER VIII

THE LYMPHATIC SYSTEM

The **lymphatic system** includes the **lymphatic** and **thoracic ducts, intermediate vessels, capillaries, lymph spaces, lymph** and a number of organs, **lymph nodes** (**lymphatic gland**), **spleen, tonsils** and **thymus body.**

The **lymph** consists of 94 per cent. of water, 3 to 4 per cent. of proteins and the remainder of sugar, inorganic salts, fatty substances, urea, also free oxygen, carbon dioxid and waste products. It is neutral in reaction and is derived from the blood by osmosis or diffusion and is returned to the blood. The lymph in the intercellular spaces carries oxygen and nutritious materials to the cells and receives the carbon dioxid and waste products. It then enters the lymph capillaries (passing through their endothelial walls), then into larger vessels and ultimately is emptied into the venous blood at the right and left subclavian-jugular vein junctions. The *cellular elements* are leukocytes; these are mainly small lymphocytes. They are passed into the blood in great numbers all of the time; some are destroyed and others are said to develop into other varieties of leukocytes. The leukocytes tend to adhere to the walls of the vessels in the circulating current. As lymph contains fibrinogen it may readily clot; this clot is white and the leukocytes entangled in the fibrin are toward the surface of the clot (postmortem).

In the lymph vessels of the small intestine, after absorption, the lymph contains a great deal of fat in the form of small droplets; the lymph here has a whitish color and is called *chyle.*

The lymph starts in the **intercellular spaces.** These are merely the tissue, or pericellular spaces and they are not lined by endothelial cells; such spaces are found between the epithelial cells of mucous membranes and glands; in the connective tissues, as the lacunæ of bone and cartilage and cornea, etc.; between the muscle fibers. They are readily outlined by the silver nitrate method.

The first vessels of the lymphatic system are the **capillaries**. These are much larger than those of the blood-vascular system, measuring from 30 to 60 microns in diameter; the diameter, however, is not constant as these vessels present successive dilatations and constrictions giving them a varicose appearance. The wall consists of a single layer of endothelial cells with very sinuous outlines. The layer of cytoplasm is thin and the nuclei project somewhat. These capillaries are closed at one end and continue into larger vessels at the other, so that the lymphatic system must be regarded as a closed system. Ordinarily the capillaries form a meshwork but in certain regions, as the villi of the small intestine, they are individual, straight, blind tubules and are called the *lacteals*.

As the lymph capillaries increase in diameter the endothelial tube becomes strengthened by the addition of a delicate fibro-elastic network. When they reach a diameter of from 0.2 to 0.8 mm. they have three coats, resemble venules and constitute small *lymph vessels*. The *tunica intima* consists of a single layer of endothelial cells resting upon the fibro-elastic subendothelial connective tissue. In this the elastic fibers have mainly a longitudinal direction but interlace somewhat. If the surrounding tissue contains a considerable amount of elastic tissue then this tissue may be absent in the vessel. The thin *media* contains some circularly arranged smooth muscle tissue. The *adventitia* is the thickest coat and consists of a network of fibro-elastic tissue in which there may be some smooth muscle tissue longitudinally arranged.

The large vessels, or **lymphatic ducts**, resemble veins more than they do arteries. The *tunica intima* is like that of the smaller vessels but the elastic tissue is usually prominent. The *tunica media* consists of fibro-elastic and muscle tissues; the muscle tissue consists of smooth muscle (more than in a vein) circularly and obliquely arranged. The elastic fibers are mainly circularly directed. The *adventitia* is quite thick and the elastic and muscle fibers are chiefly longitudinally arranged.

Blood-vessels and *nerves* are abundant in the medium and large-sized lymph channels.

Like veins the lymphatic vessels, including the lacteals, possess *valves*. These valves have the same structure as those of veins but are placed at more frequent intervals. They are numerous in the vessels of the mesentery.

Lymph vessels are found in all vascular structures except the eyeball, internal ear and the central nerve system; they are also absent from nails, hairs and cartilage.

The lymphatic structures comprise **lymphoid tissue,** including the **lymph nodes,** the **spleen, thymus and tonsils.**

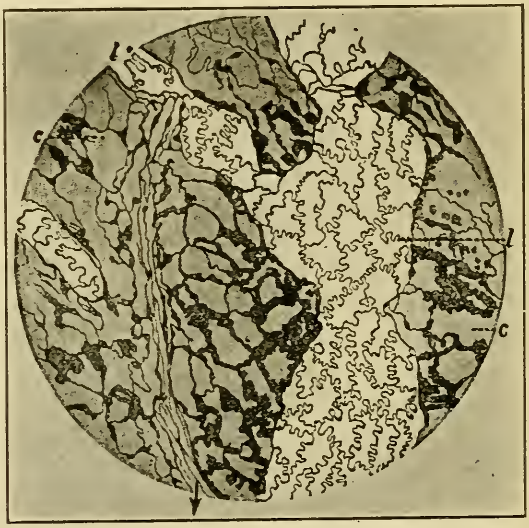


FIG. 134.—DIAPHRAGMATIC PLEURA SHOWING PART OF A LYMPH VESSEL. *c, c.* Intercellular spaces; *l, l.* lymph vessels showing the outlines of the endothelial cells. (*After Ranvier.*)

Lymphoid tissue is arranged in four forms, **diffuse, solitary nodules, agminated nodules** and **lymph nodes.**

Diffuse lymphoid tissue is an indefinite collection of leukocytes in an organ. It is found in the tunica propria of the alimentary, respiratory and urinogenital tracts. It forms the medulla of the lobules of the thymus body and the bulk of the spleen and tonsils. In the former places it consists merely of the leukocytes scattered in the areolar tunica propria. The number is usually so great that this tissue has a dark appearance and the connective-tissue portion is hidden. Under a low magnification the tunica propria has a granular appearance. In the spleen, thymus and tonsils the supportive tissue is the reticulum of the organ. The cellular elements are mainly small and large lymphocytes, only a few of the other varieties of leukocytes being present.

Solitary nodules are small dense collections of small and large lymphocytes sharply outlined, usually, from the surrounding tissue.

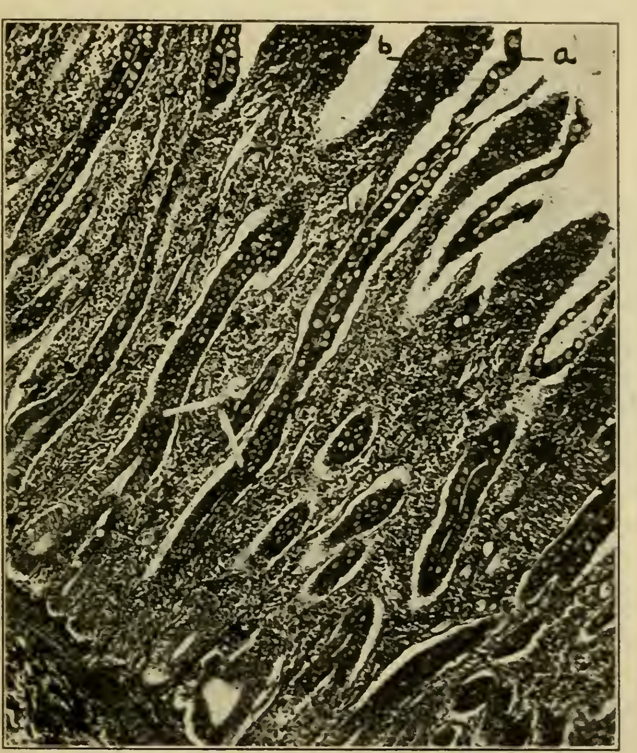


Fig. 135.—Section of the Mucosa of the Jejunum of the Cat.

a, Simple columnar and goblet cell layer separated from the core of the villus *b*; the latter is filled with diffuse lymphoid tissue. *c*, Simple tubular glands with the intervening tunica propria filled with diffuse lymphoid tissue. (Photograph. Obj. 16 mm. oc. 7.5 ×.)

The supportive tissue is said to be reticulum, the meshes of which are larger in the germinal center than at the periphery. The center of a nodule is usually lighter and is called the *germinal center;* here the cells are fewer in number, more widely separated and younger. This is the area where the cells undergo mitotic division. As the new cells are formed the excess cells are crowded and packed at the periphery of the nodule. As they form a dense mass they give to the periphery of the nodule a darker appearance. In general appearance the lobules of the thymus body are merely very large and irregular solitary nodules.

These structures are found in the submucous coat of the alimentary and respiratory tracts and in the spleen and tonsils. These and the diffuse variety are transient in character.

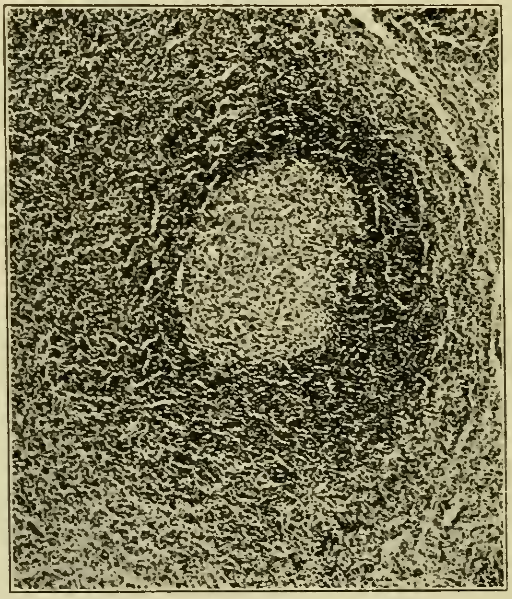


FIG. 136.—SOLITARY NODULE OF THE SPLEEN OF A MONKEY.
The light area is the germinal center. The nodule is surrounded by diffuse lymphoid tissue. (Photograph. Obj. 16 mm. oc. 7.5 X.)

The **agminate nodules,** or **Peyer's patches,** are more or less regular collections of solitary nodules forming an individual mass, sharply outlined from the surrounding tissues. Each patch is from 1 to 5 cm. in length and consists of from ten to sixty nodules, each of which shows a germinal center. Each nodule is partially or completely surrounded by a delicate capsule of white fibrous tissue, although usually the nodules merge more or less into one another. They are located in the submucosa of the ileum opposite to the attachment of the mesentery. Some state that they are also found in the jejunum. The long axis of each is directed parallel to the long axis of the bowel. They are visible to the unaided eye. Although they are said to be located in the submucosa, more commonly they are seen invading the mucosa, having broken through the muscularis mucosæ. Usually in those areas where the nodules approach the epithelial surface, the glands are absent. At the edges of the nodules the glands are seen arranged in the form of a circle. Often the villi are absent over such an area.

Each nodule has a thin-walled *artery* that passes to the center and forms a capillary plexus of wide meshes. These extend to the periphery where the blood is collected by two or more small *veins*.

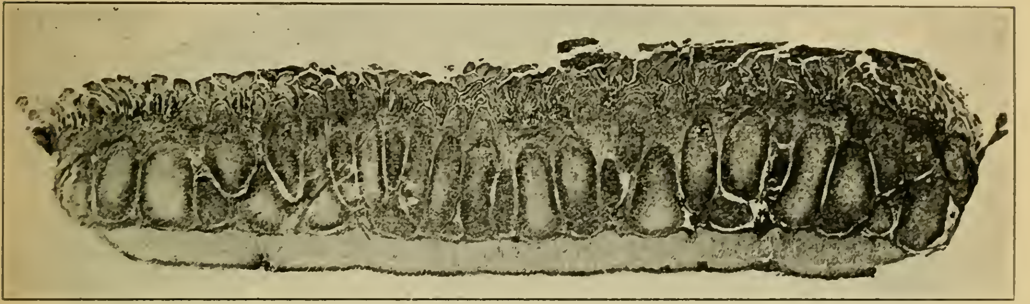


FIG. 137.—AN AGMINATED NODULE OF THE ILEUM OF A CAT. (Photograph. Obj. 48 mm.)

Lymph nodes, or **glands,** are bean-shaped organs placed in the pathways of the lymph vessels so that the lymph must filter through one, or usually more, of these structures before it ultimately enters the blood stream. They vary in size from a few millimeters to several centimeters in length. They are found distributed over the body but are more numerous in the trunk. They are most numerous in mammals, a few are found in birds, but none are found in the lower vertebrates. Each is surrounded by a capsule, has a hilus and consists of cortex and medulla.

The *capsule* consists of a thin layer of white fibrous connective tissue containing yellow elastic fibers and smooth muscle tissue. Between it at the parenchyma is seen a lymph space, the *sinus*, exhibiting a network of reticulum, that is continuous with the reticulum of the organ, on the one hand, and attached to the capsule, on the other. At regular intervals the inner surface of the capsule sends into the peripheral portion of the organ, *trabeculæ* or partial septa covered with endothelial cells. These divide the outer part of the parenchyma into a number of nearly uniform masses called the *secondary nodules;* these and the trabeculæ constitute the *cortex* of the node. The lymph sinus continues along the trabeculæ. Within the organ the trabeculæ continue into the central part or medulla where they form a large coarse meshwork for the support of the larger vessels. Throughout the organ the spaces between the trabeculæ and capsule contain a delicate meshwork of reticulum that constitutes the finer framework of the organ. This is for the support of the capillary vessels and the functionating cells of the organ. The *reticulum cells* are attached to the reticulum fibers and are said to be *phagocytic* and contain pigment granules and even erythrocytes. The trabeculæ contain some smooth muscle fibers.

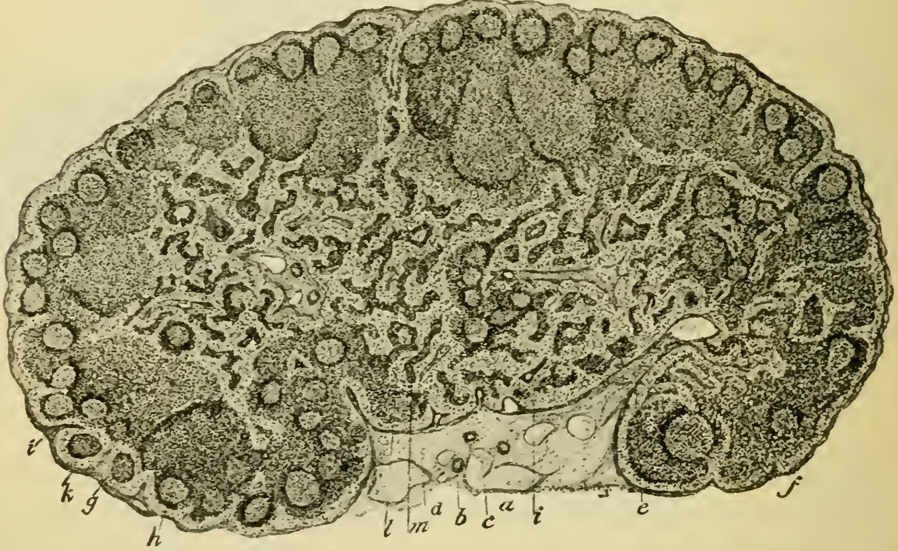


Fig. 138.—Longitudinal Section of a Lymph Node.

a, Hilus; *b*, arteriole; *c*, venous sinuses; *d*, adipose tissue; *e*, secondary nodule of cortex; *f*, vein in medulla; *g*, subcapsular lymph sinus; *h*, germinal center of secondary nodule; *i*, *i*, trabeculæ; *k*, capsule; *l*, lymph sinus; *m*, medullary cord.

The **cortex** comprises the *secondary nodules*, the *trabeculæ* and the peripheral portion of the *lymph sinus.* The *secondary nodules* are from 0.5 to 1 mm. in diameter and are just beneath the capsule and are separated from one another by the trabeculæ and the sinus. Each is a solitary nodule presenting a *germinal center* and a darker peripheral zone where the lymphocytes are closely packed. The central lymphocytes show mitotic figures. The germinal centers are not distinct in very young or old animals. Laterally the nodules may connect with one another. The medullary side of each nodule continues as a cord-like mass into the center of the organ where they anastomose or join one another. These are the *medullary cords.* The *cells* are chiefly lymphocytes, which are arranged in concentric layers around the periphery of each nodule. Other cells of the hyalin variety are found in the center of each nodule. During gestation nucleated red blood-cells may be present.

The **medulla** consists of the *medullary cords*, the *trabeculæ* and a continuation of the *sinus.* It is best developed in the mesenteric and lumbar lymph nodes.

The *medullary cords* are the cord-like continuations of the cortical nodules. Within the reticular and trabecular network of the medulla these cords anastomose and join one another to form a darkly staining coarse meshwork of dense lymphoid tissue. They consist of a reticulum supporting the lymphocytes and blood-vessels. Between the medullary cords the tissue is lighter. Here are seen the band-like trabeculæ continued from the cortex. Each consists of rather dense white fibrous tissue containing some smooth muscle tissue. Between the trabeculæ and the medullary cords is seen a delicate reticulum that marks the position of the sinus continued from the cortex. As has been shown the sinus is not a clear-cut space but a series of fine spaces between the trabeculæ and the parenchyma of the organ

At one side of a lymph node is a scar-like depression called the *hilus.* Here the cortex is absent and the medulla, mainly white fibrous tissue, comes to the surface. It is also the region where some of the vessels enter and most of them leave.

The *cells* are mainly small lymphocytes and then the hyalin cells are next. Both of these varieties are seen undergoing mitosis especially in the germinal centers of the nodules. A few finely granular oxyphils, eosinophils and mast cells occur in these organs but they are probably not formed here in any great numbers.

Many of these cells may contain fat, red cells, pigment granules and bacteria.

The *arterial vessels* enter at the hilus and divide into branches some of which continue into the trabeculæ to the cortex where they pass to the nodules and form a capillary plexus in these structures. Others pass directly to the capsule for its nourishment. Other branches leave the trabeculæ just within the hilus and pass to the medullary cords where a capillary meshwork is formed. The blood is collected by *veins* that carry the blood to the hilus where one or more vessels leave. A few small arterioles may enter at the capsule.

The *afferent lymph vessels* all enter at the surface and open directly into the capsular lymph sinus. The lymph then filters through the reticulum of the sinus and its medullary extensions toward the hilus where the lymph is collected into one or more *efferent vessels*.

The *nerves* are not numerous. Myelinated and amyelinated nerve fibers form plexuses around the vessels and supply the muscle tissue of these and the trabeculæ. They have not been demonstrated in the nodules or cords.

Lymph nodes are the highest form of lymphoid tissue. They are often collected into groups as in the axilla, femoral and inguinal regions. They are said to be somewhat inconstant as they may disappear early or change from place to place. They make certain kinds of white cells, filter the lymph and are the centers of cell destruction, and in the female, during pregnancy they may form red blood-cells.

Hemolymph nodes have been described under the circulatory system.

THE SPLEEN

The **spleen** is the largest of the lymphoid structures and is located in the abdominal cavity. It is a soft organ of a dark-red color and its shape depends upon the state of the organs surrounding it. It is surrounded by a capsule that is invested with peritoneum; within this is the splenic substance consisting of the splenic pulp and the splenic corpuscles.

The *capsule* is a rather thick layer of dense white fibrous tissue containing elastic fibers and a considerable quantity of smooth muscle tissue. Externally the capsule is covered by the peritoneum which is a serous membrane. This consists of a single layer of endothelial cells that rest upon a thin layer of fibroelastic tissue. This is thinner than the capsule proper. From the inner surface of the capsule beams of white fibrous tissue extend into the organs and form a coarse meshwork. These trabeculæ contain smooth muscle tissue and blood-vessels. The arterial vessels are thicker-wall and smaller in caliber than the veins. Within the large meshes made by the trabeculæ there is a delicate network of *reticulum*. This is for the support of the splenic substance and the smaller vessels. Upon this reticulum phagocytic reticulum cells are found.

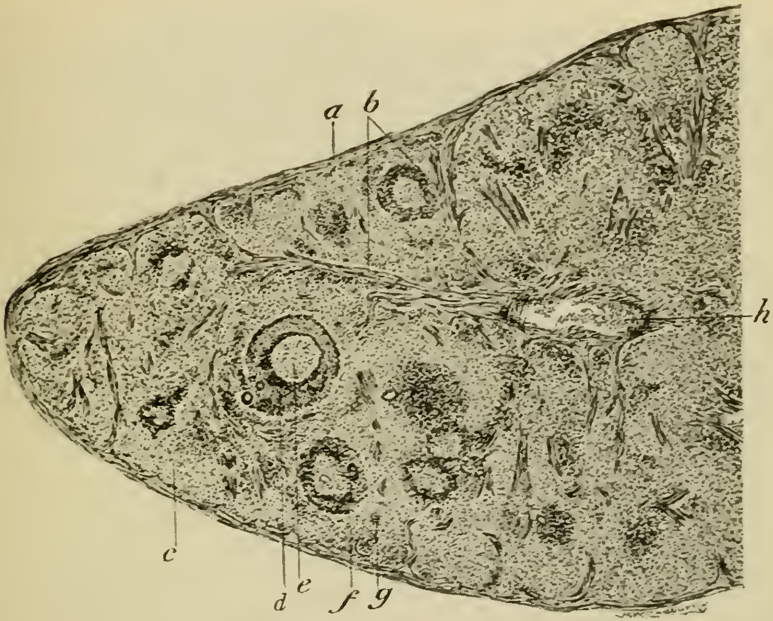


FIG. 139.—SECTION OF SPLEEN.

a, Capsule; *b*, trabeculæ, longitudinal section; *c*, pulp; *d*, splenic corpuscle; *e*, germinal center of corpuscle; *f*, eccentric arteriole in corpuscle; *g*, trabecula, cross-section; *h*, blood-vessel.

The *splenic substance* comprises the *pulp* and the *splenic corpuscles*.

The *splenic pulp* consists of diffuse lymphoid tissue comprising lymphocytes, hyalin cells and polynuclear cells; the large cells are the most numerous. In addition there are a few nucleated red cells, a great many thrombocytes, erythrocytes and many disintegrating red cells. The large number of red cells in the pulp gives the color to the spleen. The presence of nucleated red cells in the adult condition is denied by some. In fetal life and sometimes early childhood nucleated red cells may be numerous. The *splenic phagocytes* are large polynuclear cells that are ameboid as well as phagocytic; their cytoplasm usually contains many pigment granules and often erythrocytes that are undergoing disintegration. Some *giant cells*, or *megakaryocytes* are present. These are especially numerous in the fetal condition and some claim that in the adult they are absent from the spleen. The large number of disintegrating red cells in the splenic pulp has led some to call the spleen

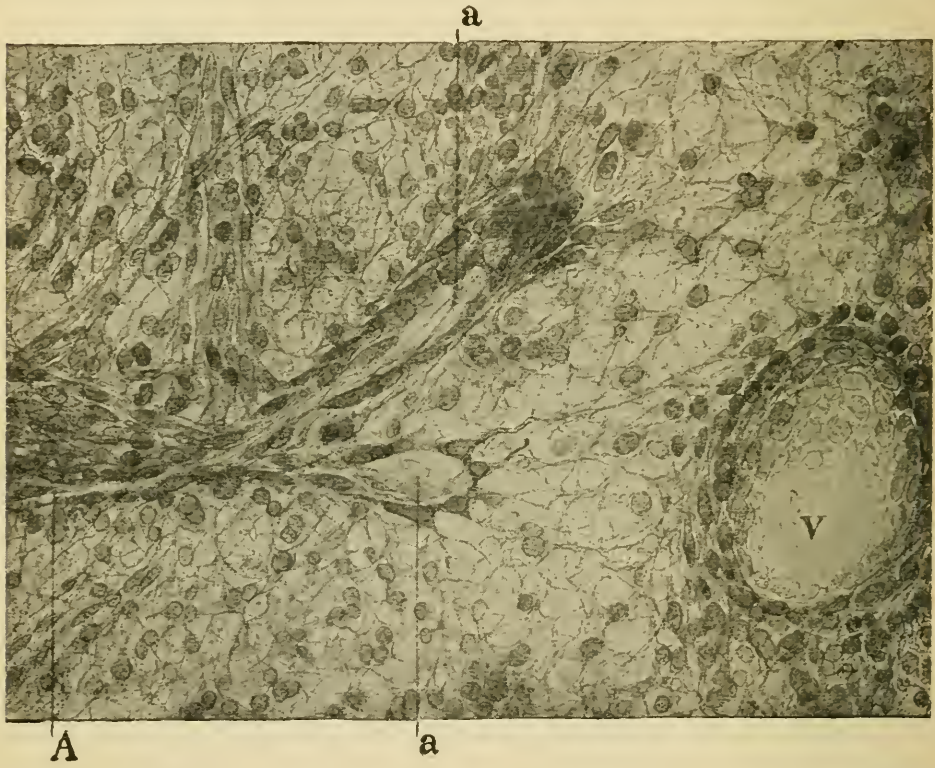


FIG. 140.—RETICULAR TISSUE SEEN IN A FROZEN SECTION OF A DOG'S SPLEEN WHICH HAD BEEN INJECTED WITH SILVER NITRATE. × 250. (*Mall.*)
A, Artery with its ampullæ (*a*); *V*, vein.

the graveyard of the erythrocytes. The uneven mixture of nucleated and nonnucleated elements gives the stained sections of the spleen a characteristic mottled appearance.

The *splenic*, or *Malpighian corpuscles* are dense collections of lymphoid tissue. Each is really a solitary nodule in which is usually seen an eccentrically placed arteriole. These vessels are not found in the ordinary solitary nodules and so this is characteristic of the structure of the nodules of the spleen. Each nodule usually shows a germinal center. It represents a collection of lymphocytes in the adventitial sheath of the arteriole.

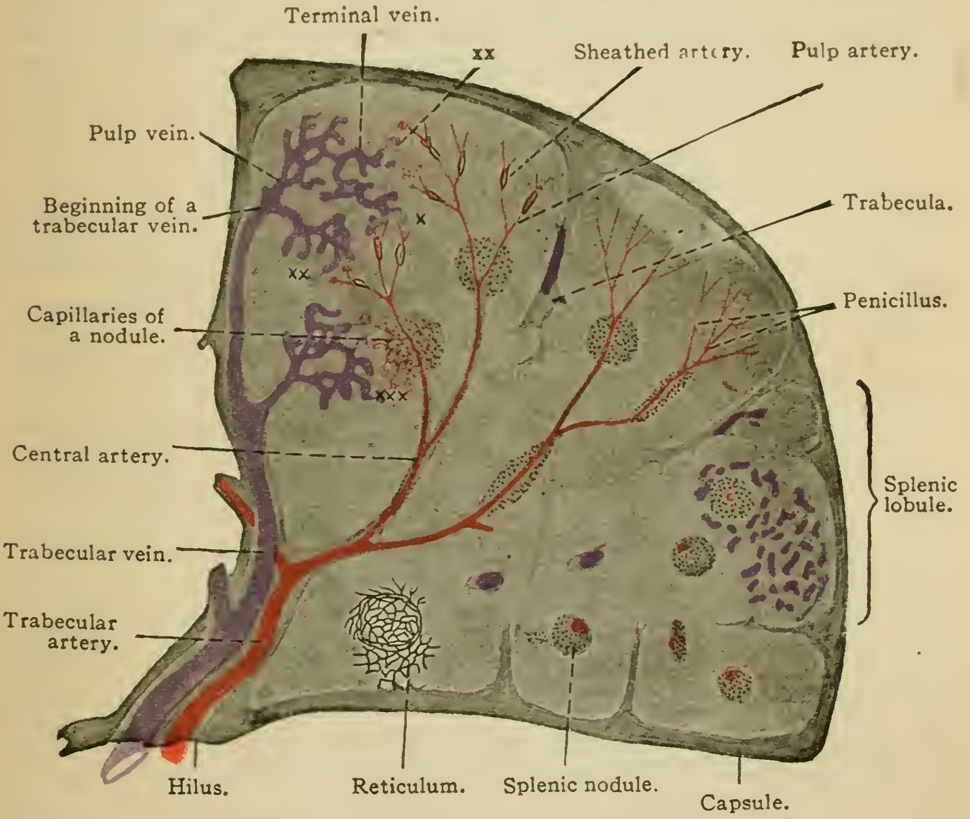

Terminal vein.
xx
Sheathed artery.
Pulp artery.
Pulp vein.
Beginning of a trabecular vein.
x
xx
Trabecula.
Penicillus.
Capillaries of a nodule.
xxx
Central artery.
Splenic lobule.
Trabecular vein.
Trabecular artery.
Hilus.
Reticulum.
Splenic nodule.
Capsule.

FIG. 141.—DIAGRAM OF THE BLOOD VESSELS OF THE HUMAN SPLEEN. (*Lewis and Stöhr.*)

At *x* is shown the direct connection of terminal arteries with terminal veins (the existence of such a connection has been questioned). At xx and xxx are the free endings of the terminal veins in the pulp and near the nodules respectively.

The *circulatory system* of the spleen is peculiar in being an *open one.* Capillaries as such do not exist and the arterioles and venules are connected to each other by blood-spaces or ampullæ. The walls of these vessels are said to be porous.

The *blood-vessels* enter and leave at the hilus. The splenic artery divides into six or more branches. As these arteries enter the spleen they branch and of these divisions some enter the pulp almost immediately while others follow the trabeculæ to their smallest divisions and to the capsule. The adventitia of the small arterioles in the pulp contains some lymphoid cells and is then called the *lymphoid sheath.* At frequent intervals the lymphoid tissue becomes very abundant forming spherical, or oblong masses called the *splenic corpuscles.* These corpuscles receive capillaries from the enclosed arteriole. The arterioles after leaving the corpuscles divide into branches which are said to be surrounded by the *ellipsoidal sheaths*; these are said to be condensations of the reticulum, without leukocytes, surrounding the terminal arteriole branches. These branches then end in the *so-called capillaries* that are really dilated channels

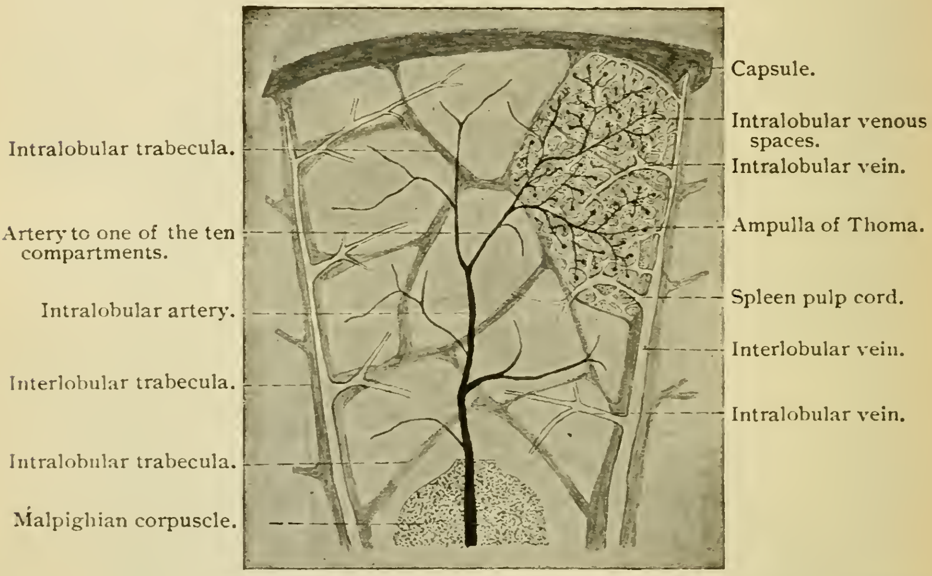

Intralobular trabecula.
Artery to one of the ten compartments.
Intralobular artery.
Interlobular trabecula.
Intralobular trabecula.
Malpighian corpuscle.
Capsule.
Intralobular venous spaces.
Intralobular vein.
Ampulla of Thoma.
Spleen pulp cord.
Interlobular vein.
Intralobular vein.

Fig. 142.—Diagram of Lobule of the Spleen. (*Mall, "Johns Hopkins Hospital Bulletin,"* Sept., Oct., 1898.) (*Böhm and Davidoff.*)

the walls of which are not complete. Some state that the capillary tubes end by opening directly into the pulp and that the terminal cells of these capillaries have branched processes that join those of the reticulum cells of the pulp. The blood is thus emptied directly into the pulp spaces. The *veins* start in this manner as venous sinuses and these are surrounded by ring-like collections of reticulum fibers and some longitudinal fibers that cause a ribbing of the sinus walls. The small veins quickly enter the trabeculæ and through them join to form larger vessels that proceed toward the hilus to form the single splenic vein.

According to Mall the spleen is divided into circulatory lobules, about one mm. in diameter, each one of which is further subdivided into *histologic units*, one for each terminal artery, or *ampulla*. These terminal vessels are covered by a lymphatic sheath, the *ellipsoidal sheaths*. The terminal ampullæ are *porous*, and continue as veins. The endothelial cells are long and slender, resembling smooth muscle cells, and are contractile. Their edges are not closely approximated. In the splenic vein the leukocytes are said to be 70 times as numerous as in the splenic artery.

The spleen is subject to rhythmic contractions, one per minute, and about 18 per cent. of its volume is lost at each contraction. These are produced by the involuntary muscle in the capsule and trabeculæ. When the cardiac impulse sends the blood into the arteries, the blood passes into the ampullæ, and through the porous walls into the pulp spaces. When the rhythmic contractions occur, the blood is forced into the veins, and, at the same time, the arteries are closed. This shows an open circulation (Mall).

The *lymphatics* are *trabecular* and *perivascular*. The *trabecular vessels* are in the trabeculæ and in the capsule; they start in the latter and get larger toward the hilus. The *perivascular lymphatics* arise in the lymphoid sheaths of the arterioles and after leaving the corpuscles two vessels are usually formed and these accompany the artery and frequently anastomose around it. As these vessels reach the hilus they join the trabecular vessels and the efferents from the spleen carry the lymph to the splenic nodes.

The *nerves* are chiefly amyelinated and are derived from the solar plexus of the sympathetic system. Plexuses are formed around the arteries and their branches and fibers pass to the muscles of the vessels and the smooth muscle of the capsule and trabeculæ.

The spleen is an important blood-cell-making organ throughout life. In fetal life it is an important center for the production of erythrocytes but by birth that function is usually lost. In certain blood diseases it may resume that function. At all times it is an important center for the formation of lymphocytes and some of the other leukocytes, though in lesser quantities. From the number of disintegrating red cells present in the pulp it must also be intimately concerned with the destruction of the useless erythrocytes. The hemoglobin derived from these cells is probably utilized by the liver in the manufacture of bilirubin and biliverdin.

THYMUS BODY

The **thymus body** is essentially a lymphoid structure, though it undergoes peculiar changes in its life history. It weighs from 5 to 11 grams at birth, increases in size and weight to puberty (40 to 50 grams) and by some is considered active until the fortieth year, losing its function after that time.

It originates as a *true gland* (epithelial organ), but soon leukocytes enter it, and cause the disappearance of the epithelium except small islands. After the sixth year, it generally undergoes further change or involution. The *lymphoid tissue is gradually replaced by adipose tissue,* so that an old thymus will show but little lymphoid tissue.

This organ is surrounded by a *capsule* of white fibrous tissue that sends in septa, which divide the organ into **lobes** and **lobules.** Within the lobule there is a delicate reticulum meshwork for the support of the parenchyma and the blood-vessels, nerves and lymphatics. Each lobule consists of cortex and medulla.

The **cortex** consists of dense lymphoid tissue and stains deeply owing to the large number of leukocytes present. The cortex may be subdivided into secondary nodules like a lymph node, by trabecular septa from the interlobular connective tissue. Germinal centers in such nodules are, however, not present.

The **medulla** consists of *diffuse lymphoid tissue,* and takes, therefore, a lighter stain; the lymphoid cells are chiefly small lymphocytes and hyalin cells and a few eosinophiles and giant cells. The supportive tissue is *reticulum*, which is coarser than in the cortex. Cortex and medulla are not always sharply differentiated from each other. At times band-like extensions of the medulla may pass from one lobule to the other. These are called *medullary cords.*

In the medulla, are found small, peculiar bodies, consisting of concentrically arranged epithelial cells; these are the *thymic corpuscles*, or *corpuscles of Hassal*. These are at first 12 to 20 microns in diameter and increase even to 180 microns. The larger ones are usually compound. New ones are constantly forming from the reticular tissue. The nucleus of a cell disappears and hyalin substance develops in the cytoplasm. The peripheral cells are usually keratinized. The center may calcify or fat may deposit. The formation of these bodies is considered a degenerative process. They are supposed to represent the remains of the epithelium, though some hold that they represent endothelium of blood-vessels. These bodies are encapsulated, and may be compound.

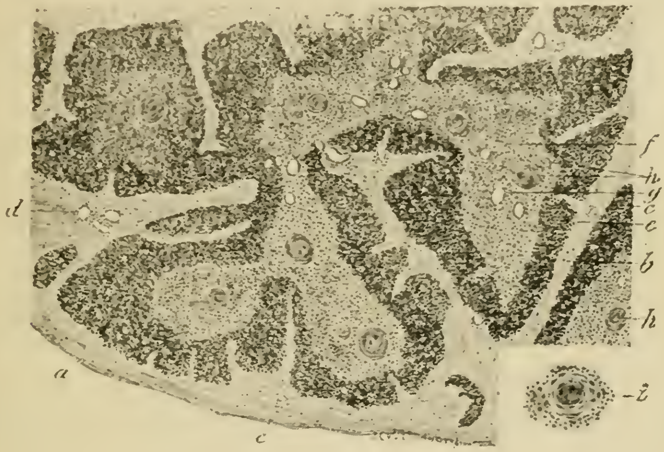


FIG. 143.—SECTION OF THE THYMUS BODY OF A CHILD.
a, Capsule; *b*, interlobular connective tissue; *c*, *c*, adipose tissue; *d*, blood-vessels in interlobular tissue; *e*, cortex; *f*, medulla; *g*, blood-vessel in lobule; *h*, *h*, corpuscles of Hassal; *i*, corpuscle of Hassal magnified.

The function of the thymus is unknown. It is a center for the formation of lymphocytes and believed by some to give rise to an internal secretion that has to do with normal growth and sexual development. Its change from epithelial to lymphoid occurs early in fetal life. The change from lymphoid to adipose tissue is variable; although its involution occurs usually from the sixth year to puberty it may retain its essential lymphoid character until after middle life and even to old age. Castration delays its involution and removal of the thymus in young animals hastens sexual maturity, especially in the male. It is also stated that its removal ultimately proves fatal.

The numerous *arteries* pass through the capsule and branch in the interlobular connective tissue. From these vessels branches pass into the cortex of the lobules and form a plexus of capillaries from which capillaries proceed to the medulla. The blood is collected into *venous channels* that pass to the interlobular connective tissue where they join to form *larger veins* that ultimately pass through the capsule and empty into the left innominate vein.

Small *lymphatic vessels* are found in the medulla and cortex of the lobules. These communicate with larger vessels in the interlobular connective tissue in which these vessels anastomose extensively. The lymph is collected into one or two vessels for each lobe and conducted to the nearest lymph node.

The *nerves* are small and chiefly sympathetic; these supply the blood-vessels.

CHAPTER IX

ALIMENTARY TRACT

The **alimentary tract** starts at the lips, and extends to the anus. It receives the food, digests it and casts off that which is undigested. The various portions perform different functions, and the lining cells differ accordingly. The inner coat is a *mucous membrane* that gives rise to *glands*, which are devices of nature for increasing the secretory surface. The absorptive surface is increased by prolongations of the mucosa into the lumen of the organ (villi of the small intestine).

The **lip** is covered externally by **skin**, and internally by **mucous membrane**. Between these, are found connective tissue and muscle.

The *skin* consists of two portions, the *epithelial*, or *epidermis*, and the *connective tissue portion*, or *derma*.

The *epidermis* is composed of *stratified squamous cells*, of which two layers, the *stratum corneum* and *stratum Malpighii* are distinct. The *stratum corneum* is the *outer*, and consists of nonnucleated scales; the *stratum Malpighii* is the *genetic* portion. Its lowest cells rest upon a *basement membrane*, and are columnar in shape. Those above are polyhedral; the latter become more flattened as the corneum is approached. The *derma* consists of white fibrous connective tissue supporting blood-vessels, nerves and lymphatics. Beneath the epithelium it is thrown into projections called *papillæ*.

The *mucous* surface is also lined by *stratified squamous* cells, that differ from the outer, however, in being larger and less readily stained. The cells rest upon a *basement membrane*, beneath which is the *tunica propria*, composed of papillated, delicate fibro-elastic tissue.

Between the tunica propria and skin, are found connective tissue and voluntary striated muscle. Near the tunica propria are to be seen small, compound tubular glands that open upon the mucous surface. At the margin of the lip these two surfaces join, and this is the *mucocutaneous junction*; here the epithelial layer is quite thick, and the cells are larger and bladder-like, resembling the epitrichial cells of the fetus.

Blood-vessels are found in great abundance, and form dense plexuses, especially around the glands.

The **mouth** is lined by a *mucous membrane*, consisting of *stratified squamous cells* resting upon a *basement membrane* and *tunica propria*. The superficial epithelial cells are not keratinized and the nuclei may be distinct. The tunica propria consists of delicate areolar tissue that supports the smaller blood-vessels, nerves and lymphatics. In addition diffuse lymphoid tissue and even solitary nodules are met with. That portion next to the basement membrane is thrown into delicate projections called papillæ; as a result of this the basal epithelial cells have a very uneven course and the tunica propria is referred to as papillated.

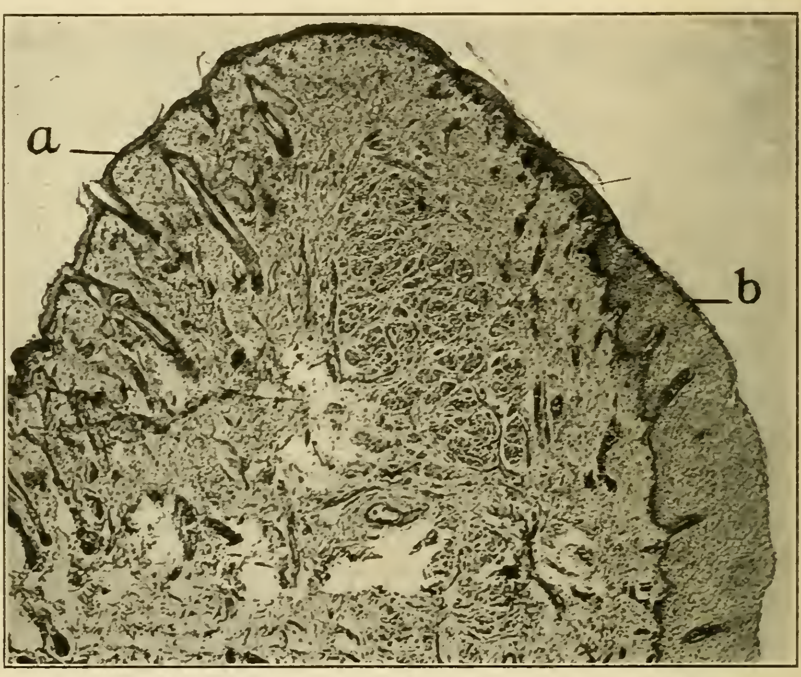


FIG. 144.—SECTION OF THE LIP OF A CHILD AT BIRTH.
a, Skin surface; *b*, mucous surface. (Photograph. Obj. 32 mm.; oc. 5 ×.)

Small salivary glands are very numerous in the mucosa and even in between the muscles; these are named according to the region in which they are found, as buccal (cheek), labial (lips), molar (opposite the molar teeth in the cheeks). These are either tubular, or tubulo-alveolar in structure. The tubular glands are mostly pure mucous glands while the mixed glands are mixed in secretion also. The mucous portion of the glands stains lightly with the ordinary plasmatic stains and the serous acini stain deeply under the same conditions. They are readily distinguished from each other under the microscope. Their appearance is also different in the different stages of secretion (rest and activity) and this will be considered with the large salivary glands.

The **gums** represent that portion of the oral mucosa covering the alveolar processes of the maxillæ and mandible and the necks of the teeth. It is dark red in color, very vascular and sensitive. It consists of *stratified squamous cells* resting upon a *basement membrane* that is very thin and indistinct. Beneath this is the *tunica propria* that consists of flattened bundles of white fibrous tissue that are arranged parallel to one another; these fibers are arranged in three ways. The vertical fibers extend from the basement membrane to the periosteum; the *horizontal fibers* run parallel to the surface; the *radiate fibers* are arranged fan-like around the alveolar margins and include fibers derived from the alveolodental membrane. Some elastic fibers are present between the bundles of white fibrous tissue which are quite dense and almost tendinous and with the fibers derived from the periosteum serve to bind the gum firmly to the alveolar periosteum.

Over the *palate* the mucosa consists of the *stratified squamous cells*, *basement membrane* and *tunica propria.* Over the front of the *hard palate* the epithelial layer and the entire mucosa is thinner than over the back portion; the tunica propria is also less papillated in front. The fibers form flat bundles that make a denser and tougher layer than in the tunica propria in general. These fibers pass from the alveolar borders toward the center of the palate in a radiate manner and are also firmly attached to the periosteum.

The *soft palate* consists of a double layer of stratified squamous cells, continuous at the free edge of the organ, enclosing between them the fibrous aponeurosis of the palate. The *epithelial cells* rest upon the thin *basement membrane* beneath which is the *tunica propria* consisting of a network of white fibrous and yellow elastic tissues. The white fibers are arranged in three directions, *horizontally* (side to side) *longitudinally* and *obliquely*. The latter fibers extend into and blend with the fibers of the *aponeurosis*. This is a dense layer of white fibrous tissue that forms the center of the soft palate and it is attached, in front, to the periosteum of the back edge of the hard palate and, behind, it extends toward the free edge of the soft palate and forms the core of the uvula. The tunica propria varies in thickness depending upon the number of salivary glands present. These glands are usually small and of the mucous variety. The mucosa is thickest at the free edge of the soft palate. The pharyngeal folds have the same general structure but the elastic tissue is more abundant.

Beneath the mucosa of the oral cavity there is a *submucous layer* that varies in thickness in different regions. It serves to connect the mucosa to the underlying structures and also for the support of vessels and glands. On the gums and hard palate it is thin and relatively dense. In the cheek and soft palate it is looser and comparatively thicker owing to the salivary glands present.

The *blood-vessels* are quite numerous and enter the submucous layer from which arterioles pass to the mucosa and form a plexus of capillaries parallel to the surface. From this plexus capillaries extend into the papillæ. The blood is collected in a similar *venous plexus* and returned from the mucosa in a corresponding manner.

The *nerves* are very numerous and terminate in various ways. The *vasomotor* nerves are sympathetic and pass to the blood-vessels. The *sensor* nerves are myelinated and terminate in free endings or special end organs. In the case of the *free endings* the nerve fiber loses its sheaths as it enters the epithelial layer and the naked axis cylinder then divides into a series of telodendrites that surround the epithelial cells and end in fine granules, or end-discs. Some free endings are found in the adventitia of the blood-vessels. The *organs* are *corpuscles of Krause* and are found in the papillæ of the tunica propria and are similar to those of the conjunctiva. Other sympathetic fibers pass to the epithelium of the glands.

THE TEETH

The **teeth** are the chief organs of mastication and are adapted for cutting, grinding, holding, etc. Each consists, anatomically, of **crown,** that portion above the gum; **root** or **fang,** that portion in the jaw; **neck,** the narrow portion between the preceding, covered by the gum.

Histologically considered, there are the **enamel** that covers the crown; the **dentin** that forms the bulk and gives the shape of the tooth; the **cementum** that covers the dentin of the fang; the **peridental membrane** that surrounds the root and holds the tooth in place; the **pulp** that occupies the pulp cavity and is the nutritive and sensitive portion of the organ. In the root of the tooth is a canal that leads into the **pulp chamber;** this is the **root canal.**

The **enamel** is the hardest substance in the body and forms a cap-like covering, of varying thickness, of the dentin. It is thickest at the cutting or occlusal surface of the teeth and diminishes in thickness as the neck is approached. It is said to consist of 97 per cent., or more, of inorganic matter and 3 per cent., or less, of organic matter. Bibra gives the composition as follows: Earthy material 96.6 per cent.; animal material 3.5 per cent. The former includes phosphate of calcium (with traces of calcium fluorid) 89.8 per cent.; calcium carbonate 4.4 per cent.; magnesium phosphate, etc., 1.3 per cent. Berzelius found only 2 per cent. of animal material and 8 per cent. of calcium carbonate.

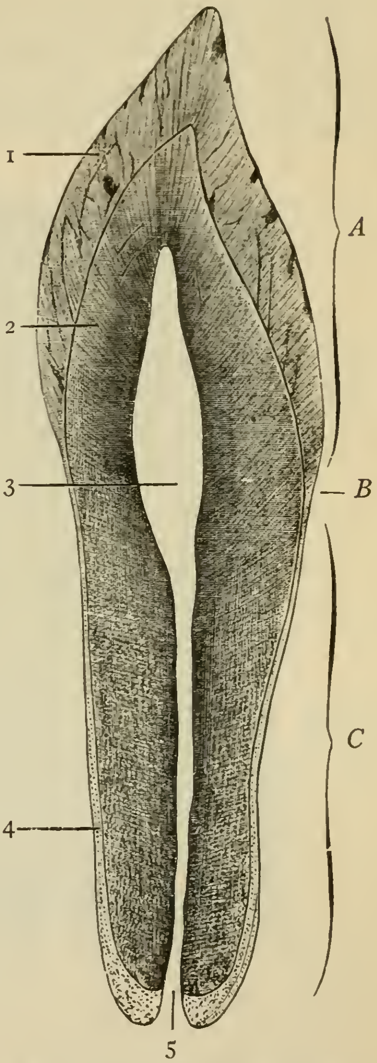


Fig. 145.—Longitudinal Section of an Incisor Tooth.

A, Crown; *B*, neck; *C*, fang; 1, enamel; 2, dentin; 3, pulp cavity; 4, cementum; 5, root-canal. (*After Stöhr's Histology.*)

The enamel consists of hexagonal enamel prisms that are arranged perpendicular to the surface of the dentin, and represent modified epithelial cells. The surface of the enamel is marked by delicate striations which indicate the enamel prisms. Each **enamel prism or fiber** is about 5 microns in diameter, has a wavy or tortuous course with its inner end fitting into a slight depression in the dentin. The prism is of the same diameter throughout, though the sides may not be straight and even. They are arranged in bundles in which the constituent prisms are parallel to one another. The various bundles are not always parallel to one another. As a result, near the surface of the tooth shorter additional prisms are found and these are the **supplemental prisms.** The prisms seem to be held together by a transparent cement which is apparently inorganic in composition. In a prepared section of the tooth are seen some *brown striations* that

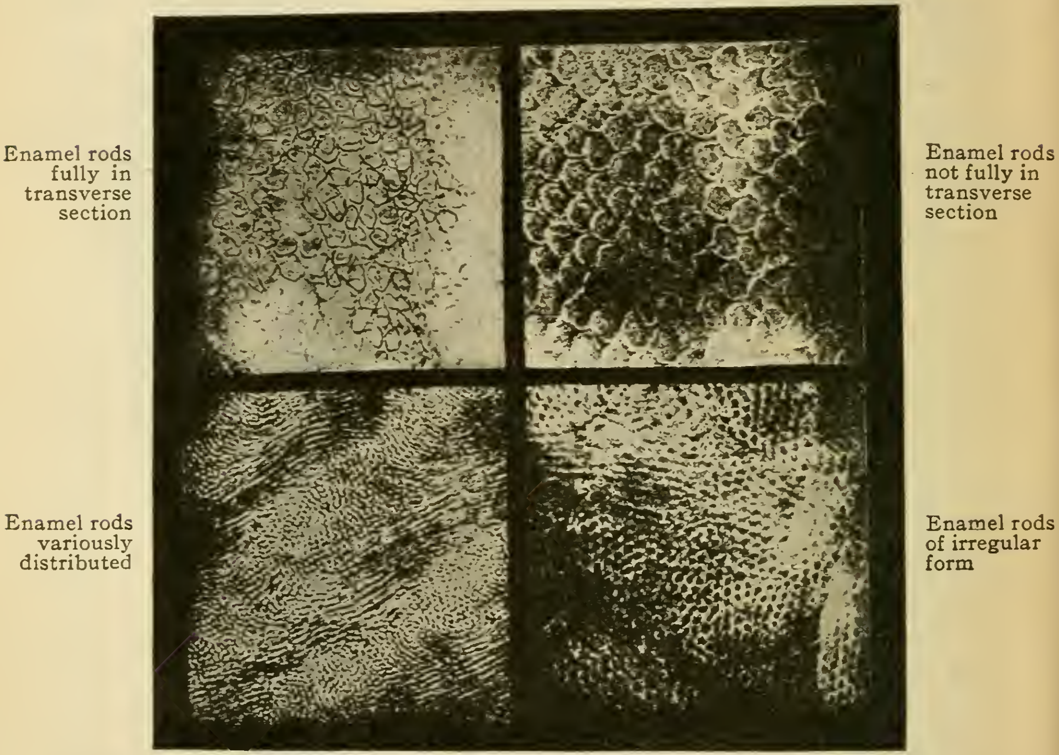

Enamel rods fully in transverse section
Enamel rods not fully in transverse section
Enamel rods variously distributed
Enamel rods of irregular form

FIG. 146.—HUMAN ENAMEL. Transverse ground sections. (*Broomell and Fischelis, after Gysi.*)

run almost parallel to the surface of enamel or dentin and in the latter instance may run the entire extent of the crown. These are the "brown striæ of Retzius." The cause of these striæ is still in dispute. Tomes believes that they represent successive positions of the enamel cap. Minute fissures may exist between the enamel bundles in the deeper portions of the enamel. At times large fissures are found that extend downward from the depressions between the cusps of the molar teeth.

When studied with reflected light the "radial lines or prism stripes of Schreger" are seen in the enamel. These are apparently due to various directions taken by the different bundles of enamel prisms, and are well marked near the surface of the dentin and less so toward the surface of the enamel. The enamel prisms are best studied in the newly formed or still growing teeth. When these are subjected to the action of acids the enamel prisms are readily dissociated or broken up.

Dentin.—This portion forms the bulk of the tooth and gives it its shape. It is yellowish-white in color, harder than bone, and represents ivory. It is everywhere covered by either enamel or cementum. It is composed of about 72 per cent. of inorganic matter and of about 28 per cent. of organic matter.

The parts of importance are the **dentinal sheaths, matrix,** and **dentinal fibers.** The **dentinal sheaths,** or **Neumann's sheaths,** are delicate tube-like masses of dense dentin that seem indestructible and will persist when the matrix has been destroyed. They extend in a curved or spiral course from the pulp cavity to the enamel or cementum, diminishing in diameter as they pass outward. Within the sheaths are spaces called **dentinal tubules,** or **canaliculi.** They radiate from the pulp cavity to the periphery and have the same curved or spiral course of the sheaths. They diminish in diameter from within outward, and terminate at the enamel or cemental surface either by anastomosing with one another, ending bluntly or opening into the interglobular spaces. Some are said to penetrate into the enamel and cementum; in the latter they communicate with the canaliculi. The pulp cavity end is usually funnel-shaped (5.5 microns), and the tubules here are closely packed so that there is very little matrix. The tubules are from 2 to 4 microns in diameter at the beginning and 0.5 to 1 micron at the peripheral end. The tubules branch toward the enamel or cementum; the branches are most numerous in the fang. These tubules may show constrictions at intervals. The curvatures of the tubules are long and short, or primary and secondary, respectively. As these occur regularly they produce the *incremental lines of Schreger.* These are lines that are parallel to the surface of the dentin.

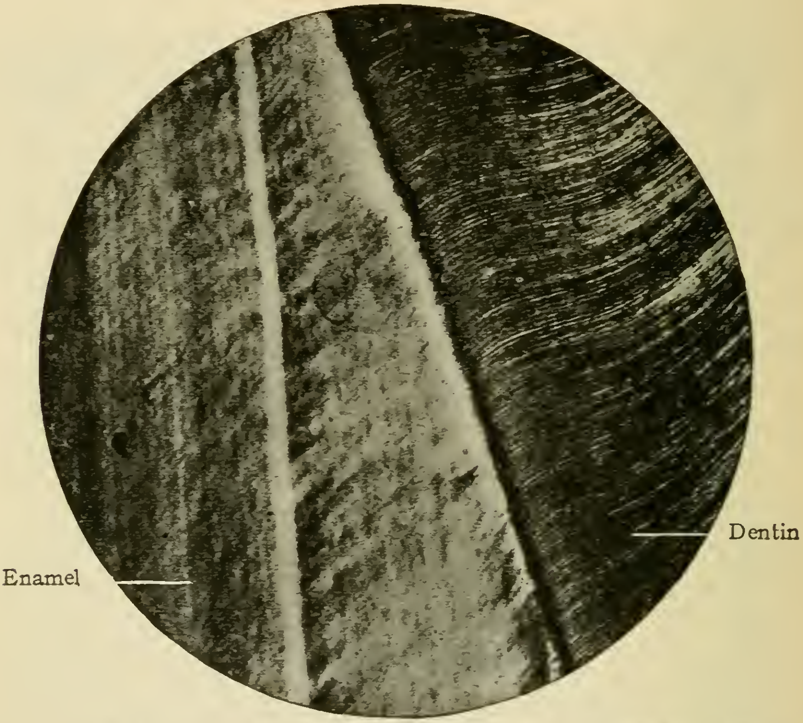


Fig. 147.—Comparison in the Appearance of the Enamel and Dentin under Low Power of the Microscope. × 40. (*Broomell and Fischelis.*)

The **dentinal fibers,** or **Tome's fibers,** represent the processes of the odontoblasts and they occupy the dental tubules, branching as the latter do and diminishing in size as the tubules become smaller. Some claim that they do not belong to the odontoblasts, but represent nerve tissue surrounded by connective tissue.

The **matrix** occupies the space between the dentinal sheaths. It consists of a more or less homogeneous dentin that is not so hard as that surrounding the canaliculi in the form of the dentinal sheaths.

Upon decalcification it can be separated into lamellæ parallel to the pulp surface. Fibers are also said to be present. It is less abundant near the pulp cavity, as the sheaths here are very close together. Farther out, as the sheaths become smaller in diameter, the matrix increases and along the margin of the dentin near the enamel, a varying number of small irregular spaces, the *interglobular spaces*, are seen; these represent areas of imperfect calcification and they are filled with a gelatinous substance. Between dentin and cementum these spaces are smaller, and under low power give a granular appearance to the area; this represents "Tome's granular layer."

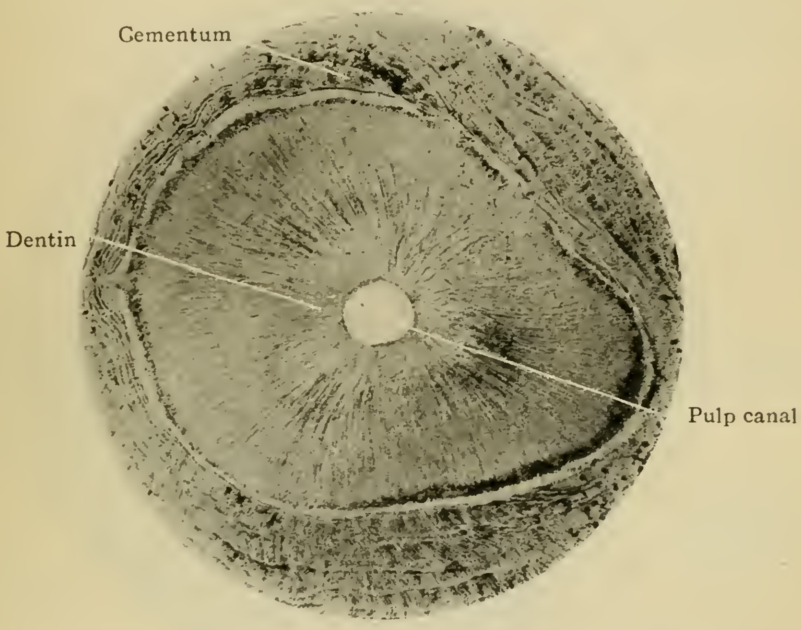


FIG. 148.—TRANSVERSE SECTION THROUGH THE ROOT OF A HUMAN INCISOR SHOWING THE DENTIN SURROUNDED BY THE CEMENTUM. × 30. (*Broomell and Fischelis.*)

Osteodentin may be deposited in the pulp cavity. This resembles bone and contains pulp and vessels. The dentinal substance may be arranged like an Haversian system and numerous tubules may radiate from the central canal.

Repair dentin may be formed in the pulp cavity, opposite to an injury upon the surface of the tooth (crown or neck). The dentinal tubules here are then blocked and if the injury be extensive the repair dentin may fill the pulp cavity.

Cementum.—The **crusta petrosa** is a bone-like substance that covers the root of the tooth. It consists of about 66 per cent. inorganic matter and 34 per cent. organic matter. It is thickest at the apex of the tooth and becomes gradually thinner as the cervix or neck is approached and ends at the lower margin of the enamel.

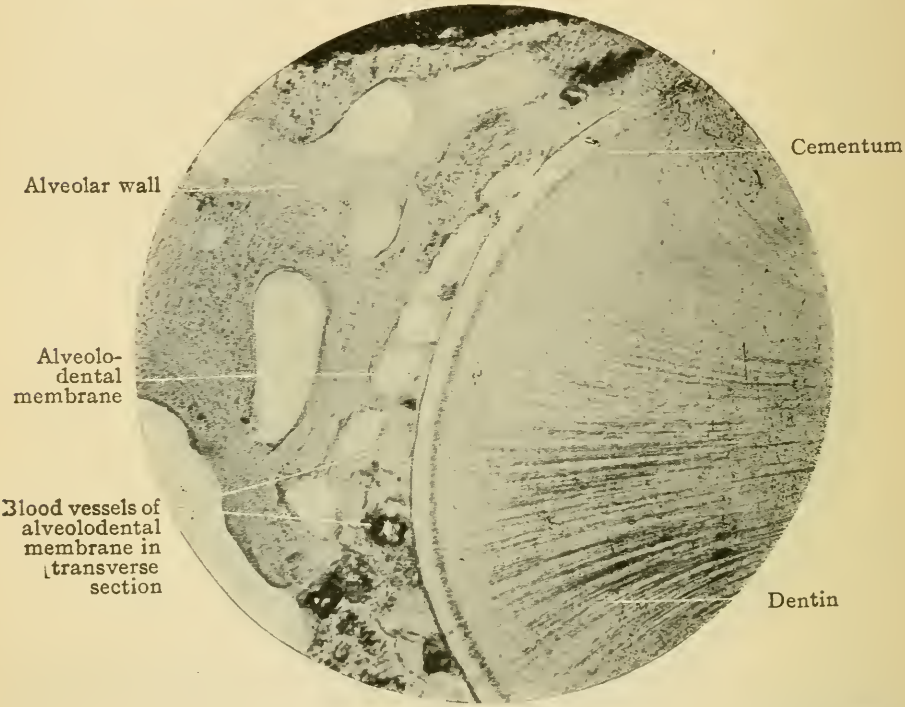

Alveolar wall
Cementum
Alveolo-dental membrane
Blood vessels of alveolodental membrane in transverse section
Dentin

Fig. 149.—Transverse Section through Root of Human Incisor and Surrounding Alveolar Wall, with Alveolodental Membrane Intervening. × 40. (*Broomell and Fischelis.*)

It resembles bone very closely, contains **lacunæ, canaliculi** and **lamellæ.** According to Schäfer Haversian systems are at times found where the cementum is thick. The **lamellæ** are about the same in number but thicker at the apex than near the cervix. This applies to young teeth. In older teeth the layers are not only much thicker near the apex but are also more numerous, the shorter added lamellæ constituting *supplemental lamellæ.* The layers may or may not run parallel to the dentin. Passing through the lamellæ at varying intervals are fibers of Sharpey. Between the lamellæ are irregular spider-like *lacunæ* that vary in size but resemble in shape and number of canaliculi, those of bone; they lie partially in one layer and partially in another and their long axes are parallel to the surface of the tooth. Extending out from the lacunæ are the *canaliculi* which usually are directed peripherally, though some are seen extending in all directions.

The **cementoblasts** occupy the lacunæ. They are oval, stellate, or elongated elements and usually correspond in direction to the lacunæ. The processes vary in length and form, and most of them extend toward the periphery, following the canaliculi.

Dental Pulp.—The **pulp** is the highly vascular and sensitive mucous connective tissue that occupies the *pulp cavity*, or *chamber* and root canals and is concerned with the nutrition and growth of the tooth. It is composed of cells and intercellular substance and contains blood-vessels and nerves.

The cells are of various varieties, the most important of which are the **odontoblasts.** These cells are found upon the surface of the pulp and form a continuous layer of cells one layer deep. They are elongated flask-shaped elements, about 40 microns in height, from which three sets of processes extend. These are *dentinal*, *pulpal* and *lateral*. The *dentinal process*, or processes, arise from the peripheral end of the cell and extend into the dentinal tubules, and they have been described under the dentin. The *lateral processes* pass from the sides of the cells to the neighboring cells, while the *pulpal processes* extend from the central ends of the odontoblasts to the deeper cellular elements of the pulp. The nucleus occupies the end of the cell next the pulp reticulum. Beneath the layer of odontoblasts there is a narrow layer of tissue almost devoid of cells, then an area of which the cells are quite numerous, and again a region, the center of the pulp, in which there are very few cellular elements. The cells are spindle-shaped, stellate and spheroid in form and possess many or few hair-like processes that pass in all directions.

The **arteries**, *apical*, of the pulp are derived from a branch that enters the root canal of the tooth; as this vessel passes toward the pulp chamber it gives off branches that form plexuses parallel to the long axis of the tooth; ultimately forming rich capillary plexuses in the neighborhood of the odontoblastic layer. The blood is collected by venous channels that anastomose freely and empty into one channel that leaves through the root canal.

The **nerves,** one or more, pass through the root canal giving off a few fibers here; in the pulp chamber branches are distributed in every direction forming arch plexuses, after losing their myelin sheaths, beneath the layer of odontoblasts. From this plexus fibers are said to pass between the odontoblasts to end in bulbous enlargements within the central ends of the dentinal tubules. Magitot claims, however, that the dentinal fibers are continuations of the nerve fibers. Mummery states that two nerve fibers from the plexus around the odontoblasts enter each tubule and this accounts for the extreme sensitiveness of the dentin. Sympathetic motor fibers supply the muscle tissue of the pulp vessels.

The **peridental,** or **alveolodental membrane,** is a highly vascular and sensitive white fibrous tissue membrane that lines the alveolar processes of the jaw and covers the roots of the teeth. It is thickest at gum and apical portions and thinnest in the middle. The fibrous elements are bundles of white fibrous tissue that pass into the cemental layers on the one hand and into the bony tissue of the jaw on the other hand, resembling Sharpey's fibers. In general, around the apex of the tooth the fiber bundles are arranged fan-like and are directed upward and outward. In the body of the tooth the fiber bundles pass directly outward from the cementum to the alveolar wall and are largest and strongest here. At the gum margin the fiber bundles pass outward and are lost in the fibrous tissue of the gum, or pass toward the adjacent tooth as the case may be.

Upon the inner surface of the membrane are found the *cementoblasts;* these are irregular flattened elements possessing a clearly defined nucleus and numerous delicate irregular processes that extend in various directions. They are evenly distributed. Upon the opposite (alveolar) surface of this membrane are the *osteoblasts* that form the bone of the jaw. In the meshes of the fiber bundles are found *fibroblasts* or connective-tissue cells and some *osteoclasts* or bone-destroying cells. The latter are large, fairly regular, oval or round cells that possess several nuclei and usually have no processes.

The *arteries* are derived from the apical artery and pass up parallel to the long axis of the tooth, giving off branches at intervals, these form capillary plexuses beneath the alveolar and cemental side of the membrane. The blood is collected by venous channels that ultimately empty into the apical vein.

The *veins* are tributary to those at the apex and are distributed somewhat like the arteries.

The *functions* of the alveolodental membrane are *physical* and *sensor.* It holds the tooth in place, returns it to its normal position when slightly rotated or displaced; upon one side it forms cementum and upon the other it forms bone.

Nasmyth's Membrane.—This enamel cuticle is a thin indestructible membrane covering the enamel of the unworn tooth. It is said by some to be the remains of the enamel organ, while others claim it is a continuation of the cementum. The *former* seems the more probable origin. It forms a protective covering and is horny in nature. It resists the action of strong acids and also prolonged boiling. With silver nitrate outlines like those of pavement epithelium are produced. It is made up of short, uncalcified prisms that are flattened in shape and represent the last formed portions of the enamel prisms before calcification takes place.

THE TONGUE

The **tongue,** like the teeth, occupies part of the mouth cavity. It is covered by a **mucous membrane** that consists of *stratified squamous* cells, *basement membrane* and *tunica propria,* which, along the sides and base, is papillated. The superficial surface of the epithelium of the sides and under surface of the tongue is regular and even in its course and the tunica propria is thick throughout. The upper surface, or *dorsum,* is characteristic. It is continuous with the mucosa lining the oral cavity. Its apical two-thirds is covered by minute projections, called *papillæ;* of these there are three varieties, **filiform, fungiform** and **vallate.** The central portion consists chiefly of voluntary striated muscle that forms the bulk of the organ.

The **filiform papillæ** are *cone-shaped projections* of the *tunica propria,* covered by the *stratified squamous* cells, the outer ones of which are hard and horny. They vary in height from 0.5 to 2.5 mm. The central part of a papillæ consists of white fibrous tissue, which is thrown into small *secondary papillæ* that are not visible externally. These papillæ are the most numerous, and are scattered over the whole of the apical two-thirds. They are directed backward, and are the ones that produce the scratching sensation when the hand is licked by a lower animal. In these animals these papillæ are very long and the amount of keratinized epithelium is great.

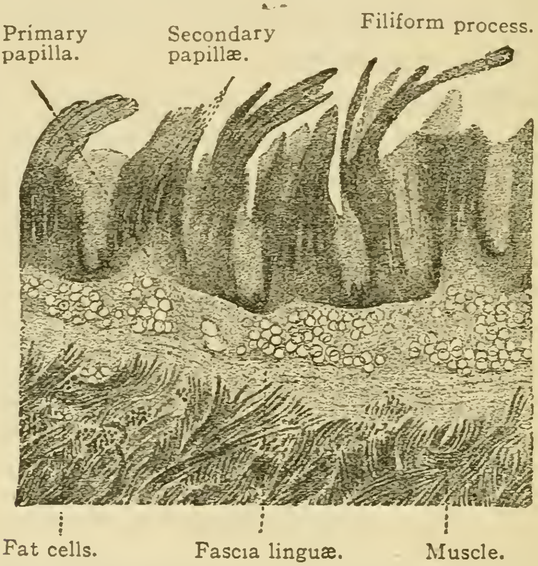


FIG. 150.—FROM A LONGITUDINAL SECTION OF THE DORSUM OF A HUMAN TONGUE. × 12. (*Lewis and Stöhr.*)

The **fungiform papillæ** are flat-topped, table-like structures, in which the sides are parallel. They have secondary papillæ, and are scattered like the filiform variety, but are less numerous. Each consists of a large central core of tunica propria that usually has secondary papillæ. In the stratified squamous cells covering these papillæ taste-buds are occasionally found. They are usually not over 1.5 mm. high.

The **vallate papillæ** are the most important. While the top is flat, the sides usually converge and give this variety a narrow base. *Secondary papillæ* are found *only on the upper portion.* Each papilla is surrounded by a little *vallum,* or *ditch,* hence the name; this is due to the fact that these papillæ are beneath the general surface level of the mucosa of the tongue.

These papillæ are the least numerous, and are found only in one area. Ten to fifteen arrange themselves like a letter V, with the apex at the *foramen cecum*, a little depression that lies at the boundary of the apical two-thirds and basal one-third of the tongue. These papillæ contain **taste-buds** along their sides.

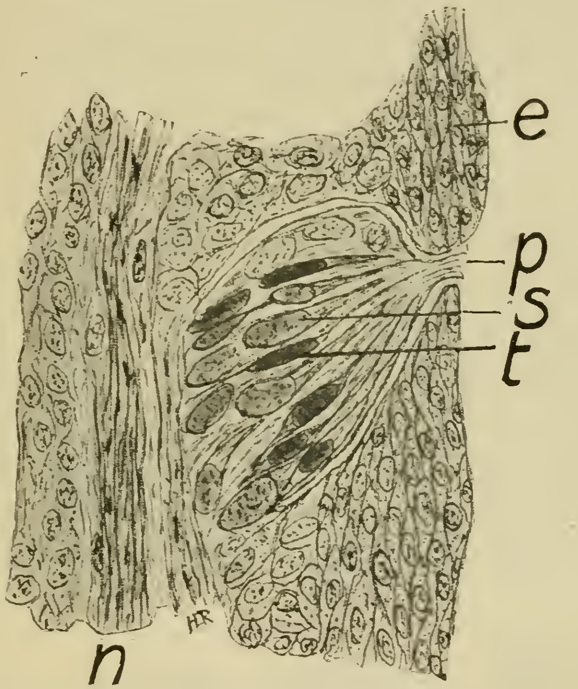


FIG. 151.—SECTION OF A TASTE-BUD OF A RABBIT.
e, Epithelium; *p*, taste pore with gustatory hairs; *s*, sustentacular cells; *t*, gustatory cells; *n*, nerve fibers. (*After Ranvier.*)

The **taste-buds** are the organs of taste and lie in the epithelial layer of the vallate papillæ as well as in the epithelial layer of some of the fungiform papillæ, in the epithelium of the soft palate, uvula, papillæ foliatæ and the ventral surface of the epiglottis. They are ovoid or barrel-shaped structures. The superficial extremity is narrow and extends nearly to the surface of the epithelial layer; the deeper part is broader and rests upon the basement membrane. At the superficial end there is a small opening called the *gustatory pore*, that leads through a short canal to the surface of the papilla.

Each bud consists of two kinds of cells, the *outer*, stave-like elements called the *sustentacular cells;* the *inner, neuroepithelial cells.*

The *sustentacular*, or *supporting cells*, are elongated elements the outer ends of which are pointed and form the boundary of the taste-pore. The basal extremities of these cells, are broad and irregular and rest upon the basal cells, to which they may be connected by protoplasmic processes.

The *gustatory cells* are of the *neuroepithelial type.* They are so thin that the nucleus forms a large bulge near the center of each cell. The basal extremity of each cell is usually branched and connected to the basal cells by delicate protoplasmic processes. The outer extremity is continued as delicate hair-like process that extends into the epithelial canal beyond the taste-pore and almost to the surface of the epithelium of the mucosa of the papilla. The finely granular cytoplasm contains a deeply staining, rod-shaped nucleus.

The *basal cells* are flattened elements that lie at the base of the taste-bud. The cytoplasm is small in amount and extends as many processes that connect with the other cells of the taste-bud. The nucleus contain but little chromatin. These cells are supposed to be supportive in function.

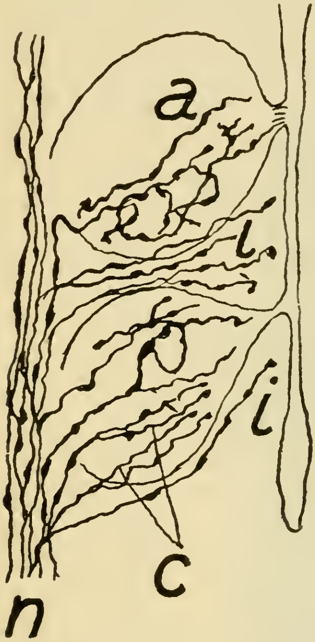


FIG. 152.—GOLGI PREPARATION OF THE NERVE FIBERS OF A TEST-BUD.

a, Intragemmal fibers; *i*, *i*, intergemmal fibers; *c*, circumgemmal fibers; *n*, nerve fibers. (*After Retzius.*)

The *nerve fibers* arise from the subepithelial plexus of nerve fibers. These terminal fibers end in three ways. Some enter the organ (*intragemmal*) where they divide into fibrils that are varicose and end in small knobs between the neuroepithelial cells. Others surround the taste-bud (*circumgemmal*) and the fibrils terminate upon the sustentacular cells. Others end between the neighboring epithelial cells of the mucosa (*intergemmal*).

Beneath the mucosa is found the **musculature** of the tongue. This consists of the voluntary striated variety, arranged *longi-*

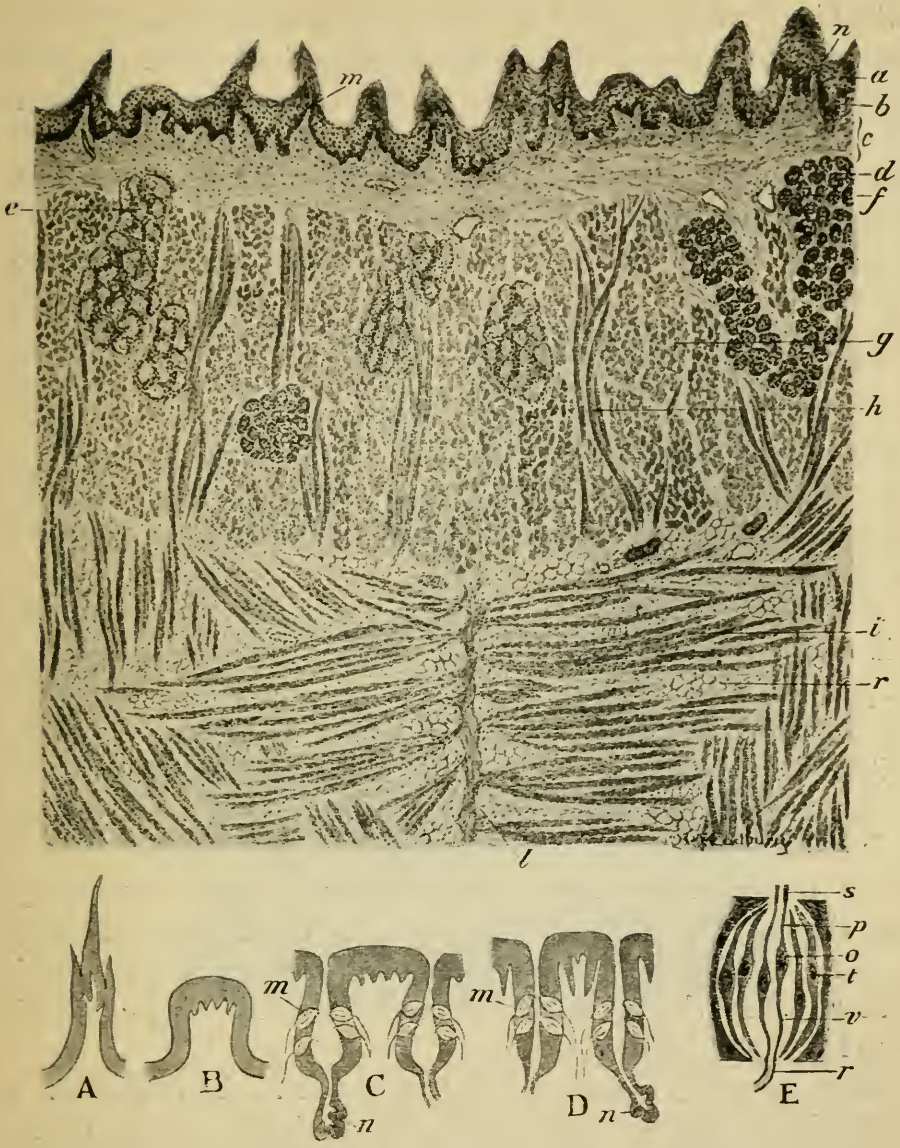


Fig. 153.—Cross-section of Tongue.

a, Stratified squamous cells; *b*, basement membrane; *c*, tunica propria; *d*, serous glands; *e*, mucous glands; *f*, venule; *g*, longitudinal muscle fibers; *h*, vertical muscle fibers; *i*, transverse muscle fibers; *l*, septum; *m*, filiform papilla; *n*, secondary papillæ; *r*, adipose tissue. A, Filiform papilla. B, Fungiform papilla. C, D, Circumvallate papillæ—*m*, *m*, taste-buds; *n*, *n*, glands. E, Taste-bud—*o*, nucleus of neuro-epithelial cell; *r*, nerve fiber; *s*, gustatory hair; *t*, sustentacular cell; *v*, neuro-epithelial cell.

tudinally, vertically and *transversely.* The longitudinal fibers are arranged in bundles that lie beneath the tunica propria and extend around the tongue. They are separated by small bundles of vertical fibers. In the center, the fibers are vertical, oblique and transverse, and are separated in the middle line by a little partition, or *septum.* This consists of white fibrous tissue, and arises at the base, but does not reach the tip. It varies in height, being higher in the middle than at either end. In the muscular portion, small salivary glands are often found. Occasionally, branched muscle fibers are found.

The mucosa of the true base of the tongue, basal one-third, possesses *no papillæ.* The epithelial surface, however, is not smooth and regular but presents a large number of little rounded elevations each of which shows a small central opening. These elevations indicate the presence of the *lingual tonsils* and the openings are the orifices of the crypts.

The *epithelium* is of the stratified squamous variety and these cells rest upon a *thin basement membrane* and a rather thick *tunica propria* that consists of areolar tissue. The *crypts* are tubular extensions of the epithelium of the surface of the tongue and these epithelial cells are the lining cells of these tonsillar crypts. In the tunica propria surrounding each crypt there is a solitary nodule. It is this nodule of lymphoid tissue that bulges the epithelium and forms the rounded elevations upon the surface. Lymphocytes pass through the epithelial layer and enter the crypts of the lingual tonsils. The basal one-third of the tongue represents an extensive, widespread but shallow tonsil, a part of the tonsillar ring surrounding the pharyngeal orifice.

Minute *salivary glands* are very numerous in the tongue and are called *lingual glands.* These are usually buried in between the muscle bundles and their ducts pass to all surfaces. Upon the ventral (under) surface near the tip, under the mucosa, are two of the largest glands and these are called the *apical glands.* The glands are especially numerous at the root of the tongue. These glands are of both the mucous and serous types.

The tongue is very vascular and is supplied by the *lingual artery* chiefly. This artery and vein are deeply buried and from the artery branches pass to the deeper parts of the tunica propria and form a plexus of vessels. From this plexus of capillaries others are given off that pass to the superficial portions of the tunica propria and in the papillæ form loops that are characteristic. From the deeper side of the plexus vessels supply the musculature and glands. The blood is returned by *venous channels* that have a corresponding course.

The *lymphatics* are *superficial* and *deep*. The former start in the intercellular spaces beneath the epithelium; around the lingual tonsils these lymphatics are very numerous and the capillaries form plexuses around the nodules. The *deep set* is located near the surface of the musculature and receives the lymph from the superficial set and also from the deep structures of the tongue. The *efferents* from this plexus carry the lymph to the lingual and deep cervical lymph nodes.

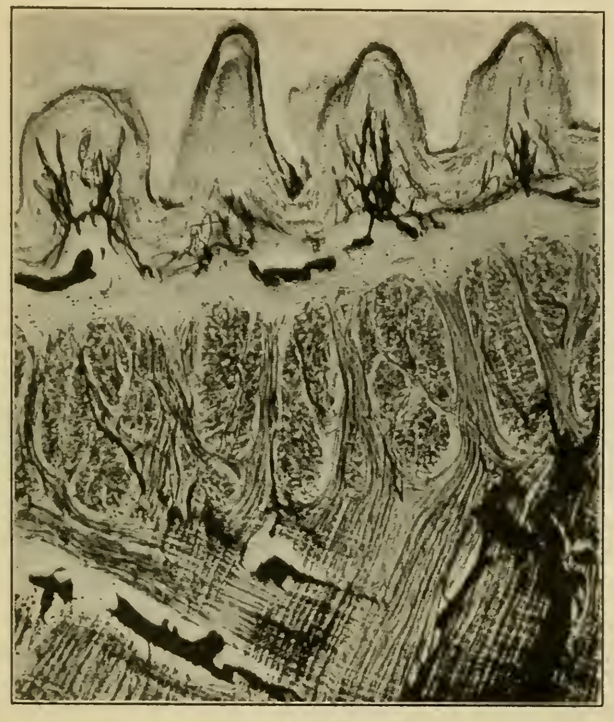


Fig. 154.—Cross-section of an Injected Tongue.
Note the abundant vessels in the papillæ. (Photograph. Obj. 32 mm.)

The *nerves* are from the cerebrospinal and sympathetic systems. The cerebrospinal nerves are *sensor* and *motor*. The *sensor* are for general sensibility and special sense of taste. The former terminate in free endings in the tunica propria of the papillæ and the deeper connective tissue; some terminate in muscle spindles. The nerves of special sense of taste pass in small bundles of fibers to the bases of the papillæ containing the taste-buds. These form a plexus beneath the epithelial cells and from this plexus fibers are distributed to the interior of the taste-buds, to the surface of the taste-buds and to the surrounding epithelium. In the latter instance the naked fibers end between the epithelial cells.

THE TONSILS

The **palatal tonsils** are located at the beginning of the pharynx one on each side of the base of the tongue, between the glossopalatal and glassopharyngeal folds. They are essentially lymphoid in structure but being so intimately related with the alimentary tract they will be described here. Each is about 2 to 2.5 cm. long, 18 mm. wide and 12 to 15 mm. thick.

Upon its *pharyngeal surface* each is covered by a continuation of the mucosa of the oral cavity. This consists of *stratified squamous cells* that rest upon a thin *basement membrane* beneath which is the *tunica propria* consisting of areolar tissue. *Laterally* the organ is surrounded by a *capsule* of rather dense white fibrous tissue that separates it from the surrounding tissues. This capsule sends in trabeculæ that form the gross framework of the organs; within this there is a delicate meshwork of reticulum that supports the functionating cells, small blood-vessels, nerves, and lymphatics. In the trabeculæ are found the larger vessels and nerves. Upon the pharyngeal surface of the organ are noted a number of openings that are the orifices of the *tonsillar crypts*. These crypts are usually long and tortuous and those of the upper portion of the structure are said to pass downward and laterally. These crypts are lined with stratified squamous cells continued from the pharyngeal surface, and in this epithelial layer are seen varying numbers of leukocytes called *salivary corpuscles*. These are ameboid leukocytes that wander through the epithelium into the crypts. When examined fresh the granules of the cells may exhibit Brownian motion. The epithelium in areas may often show degenerative changes.

Within the reticulum is seen the *parenchyma* that is composed of lymphoid tissue of the diffuse and solitary nodule varieties. The cells are chiefly small and large lymphocytes. The solitary nodules all show germinal centers and these structures are arranged in a single row around the crypts; the remainder of the intercrypt reticulum is filled with the diffuse lymphoid tissue which will also fill in such spaces as are not occupied by the solitary nodules. The ducts of small mucous glands are said to empty into the crypts at times.

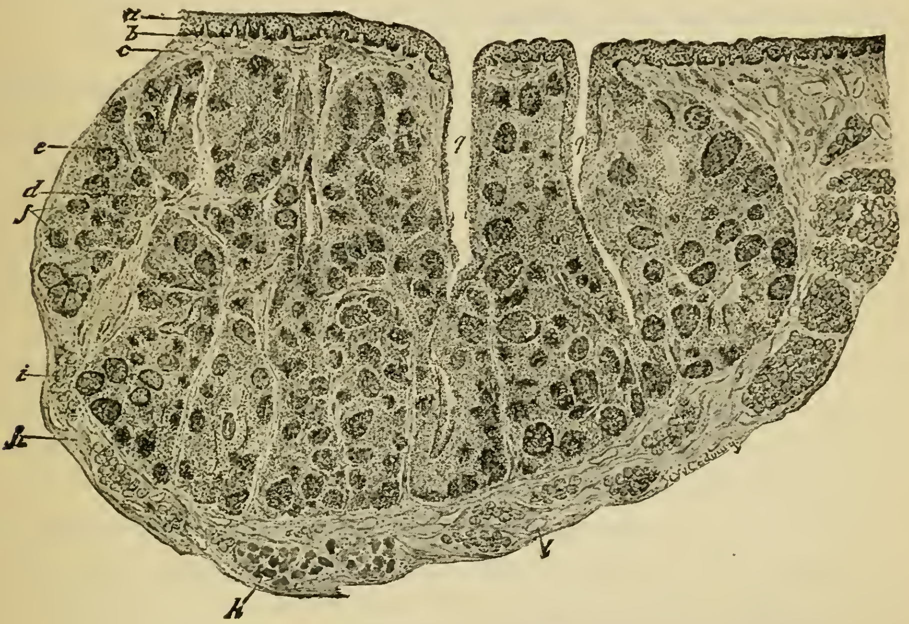


FIG. 155.—VERTICAL SECTION OF A HUMAN PALATAL TONSIL.
a, Stratified epithelium; *b*, basement membrane; *c*, tunica propria; *d*, trabeculæ; *e*, diffuse lymphoid tissue; *f*, nodules; *h*, capsule; *i*, mucous glands; *k*, striated muscle; *l*, blood vessel; *q*, pits.

Under the palatoglossal fold there seems to be an area that corresponds to a *hilus* as the larger vessels seem to enter here. Other *arterial vessels* enter at different points on the capsule. These vessels all branch and the larger divisions follow the trabeculæ; from these vessels smaller branches extend into the substance of the organ and form capillary plexuses in the diffuse tissue and around the nodules. The blood is then collected and returned by *venous channels*.

The *lymphatics* are also numerous. The lymph channels form plexuses that surround the nodules and empty into a peripheral vessel beneath the fibrous capsule.

THE PHARYNX

The **pharynx** is a musculo-membranous bag that connects the oral cavity with the esophagus. It communicates also with the larynx, the nasal cavities and on each side with the middle ear through the auditory tube. There are three divisions, the *nasopharynx*, the *oropharynx* and the *laryngopharynx*. It consists of three coats *mucous*, *fibrous* and *muscular*.

The *mucous coat of the nasopharynx* is lined with stratified ciliated cells that rest upon a delicate basement membrane beneath which there is the areolar tunica propria. Goblet cells are also numerous in the epithelial layer. In the *tunica propria* there are usually some small mucous glands and lymphoid tissue. The latter is of the diffuse form and solitary nodules are very numerous, especially on the dorsal wall. When these hypertrophy in the child they are called *adenoids*. This lymphoid tissue represents the *pharyngeal tonsil*. The tunica propria is firmly adherent to the bony dorsal boundary of the pharynx, but laterally and ventrally it is loosely attached to the muscles of the pharynx and palate.

At the side of the nasopharynx the epithelial cells are continuous with those of the auditory tube. The tunica propria of the pharyngeal extremity of the auditory tube contains a considerable quantity of lymphoid tissue that constitutes the *tubal tonsil*.

In the *oropharynx* and *laryngopharynx* the epithelium is of the stratified squamous variety. These rest upon a basement membrane and a rather thick tunica propria that contains thin-walled bloodvessels and the ducts of some mucous glands that lie deeper. The epithelial surface of the tunica propria is usually papillated.

The *fibrous coat* is the middle portion of the organ; this consists of large bundles of connective tissue fibers and numerous yellow elastic fibers that are longitudinally directed. Some of both kinds of fibers extend into the tunica propria and muscle coat. This fibrous coat takes the place of a submucosa as it supports the larger vessels and nerves.

The *muscle coat of the pharynx* is the same throughout. It consists of voluntary striated muscle, the various constrictors of the pharynx, that have an oblique direction. In places the muscle tissue is intimately attached to the periosteum of the adjacent bones but in other places it is not and here there is considerable loose areolar tissue that serves to connect the pharynx to the neighboring tissues or organs. In the connective tissue between the muscle bundles are the mucous glands above mentioned.

The *blood-vessels* and *lymphatics* are numerous; the main vessels lie in the fibrous coat and from this smaller vessels extend into the mucous and muscle coats and form plexuses of capillaries in these, especially around the glands.

The *nerves* are also numerous. Those from the cerebrospinal system are both *motor* and *sensor*. The former pass to the voluntary muscles and the latter to the mucous membrane. Sympathetic fibers are also present and these pass to the blood-vessels and glands.

ESOPHAGUS

The remainder of the **alimentary tract** is *tubular*, and possesses four coats, **mucous, submucous, muscular** and **fibrous.** The **mucosa** is further subdivided into four layers, *epithelium, basement membrane, tunica propria* and *muscularis mucosæ.*

In the **esophagus,** the **mucous coat** is lined by *stratified squamous* cells which upon the lumen surface run an even course. These rest upon the *basement membrane*, beneath which is the *papillated tunica propria.* These papillæ are tall and slender and extend for quite a distance into the epithelial layer. The tunica propria consists of yellow elastic and white fibrous tissues, in which the capillary vessels form a delicate network beneath the epithelium; the ducts of the glands pass through this layer on their way to the surface. These ducts are lined by tall columnar cells at first but in the epithelial layer these cells are replaced by several layers of flattened elements. Diffuse lymphoid tissue and even solitary nodules may be present. The *muscularis muscosæ* consists of involuntary, nonstriated muscle fibers, circularly and longitudinally arranged. In the upper portion of the esophagus, this layer is often wanting, but in the lower part it is always present. In the resting condition, the mucous and submucous coats are thrown into *longitudinal folds.*

Although the general epithelium is of the stratified squamous variety occasionally patches of *ciliated*, or *columnar epithelium* are found in the upper third. These may be retentions of fetal cells as in fetuses up to birth, such patches are frequently found in the esophagus. In the resting condition the walls of the esophagus are in contact and the lumen almost obliterated. In this condition the mucosa and submucosa are thrown into extensive longitudinal folds.

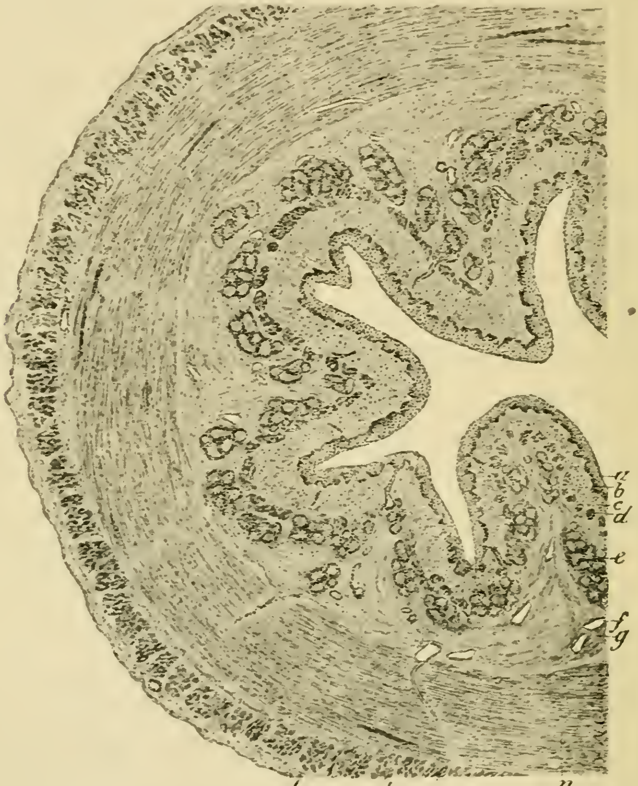


FIG. 156.—CROSS-SECTION OF ESOPHAGUS.

a, Stratified squamous epithelium; *b*, basement membrane; *c*, tunica propria; *d*, muscularis mucosæ; *e*, esophageal gland; *f*, blood-vessel; *g*, submucosa; *k*, outer longitudinal muscle; *l*, fibrous coat; *n*, inner circular muscle.

Some short branched tubular glands, resembling those of the cardiac end of the stomach, are found in the upper part of the esophagus. These tubules are lined throughout with simple columnar cells as well as the neighboring esophageal surface. In addition the secretion portions may contain some *parietal cells*. Although they do not respond to stains as the deep mucous glands they are considered mucous in type. These glands involve only the mucous coat and are called the *upper cardiac glands* or the *superficial glands* of the esophagus.

The *lower cardiac glands* are found at the lower part of the esophagus close to junction with the cardiac portion of the stomach. These glands are similar to the preceding and are continuous with the gastric glands.

The **submucous coat** is composed of coarser bundles of white fibrous tissue, which forms a loose network for the support of the large blood-vessel trunks. In this coat are seen a number of glandular structures, the *esophageal glands*, which are apparently mucous, as they stain lightly with ordinary stains but respond well to the mucin stains. They send their ducts through the mucous coat. As the stomach is approached, these glands become more numerous, and may even be found in the mucosa. They are of the compound alveolar type; *crescents* are absent in these glands in man. In herbivorous animals these glands are absent. In carnivorous and omnivorous animals they are very numerous seeming to indicate that they are important in the chemistry of digestion.

The **muscle coat** consists of muscle fibers arranged in two layers, *inner circular* and *outer longitudinal*. It is said that the layers are thicker here than in any other part of the alimentary tract with the exception of the caudal end of the intestine. In the upper third these fibers are of the voluntary striated variety, in the lower third smooth and in the middle portion, mixed. The involuntary nonstriated variety continues throughout the remainder of the tract. In the upper part of the esophagus the longitudinal muscle is arranged in *three bands*, one ventral and two lateral. Occasionally some voluntary fibers are found in the lower third in man, while in some animals these fibers predominate throughout the esophagus.

The **fibrous coat** consists of fibro-elastic tissues, and connects the organ with surrounding tissues. It sends in bundles between the muscle bundles, of which they are said to form the perimysium.

The main *blood-vessels* lie in the submucosa and form a longitudinal network. From this smaller branches pass to the mucosa, the muscularis mucosæ and the muscular coat. In these extensive capillary plexuses are formed. In the submucosa special plexus surround the glands. The blood is returned by venous channels in a corresponding course.

The *lymphatics* are mucous and submucous. The mucous vessels start in the papillæ and connect with the channels in the submucosa which also receive the lymph from the muscle coat. The solitary nodules present are usually surrounded by sinus-like lymph vessels.

The *nerves* are both myelinated and amyelinated. They form two plexuses, one between the layers of the muscle coat and the other in the submucous coat. In these plexuses there are many large ganglia containing large ganglion cells. From the myenteric plexus myelinated nerve fibers (from the vagus) pass to the voluntary striated muscles where they terminate in motor end-organs. Other amyelinated nerve fibers pass to the smooth muscle tissue of the muscle coat and the muscle of the vessels. From the submucous plexus amyelinated fibers pass to the muscularis mucosæ and the glands and epithelial lining of the organ where they terminate in free endings.

STOMACH

The **stomach** is the first part of the tract in which the food rests for any length of time, and in which active digestion and possibly some absorption occur. Although very large, it still represents a tube, and has the four coats above mentioned. It is divided into three portions, the **cardia, fundus** and **pyloric end.** They pass into one another insensibly, and the structure of the first two parts is practically the same.

The **mucous coat** is rather thick and presents a great change over that of the esophagus, showing a higher degree of specialization. The epithelial change is abrupt. In it are seen, with the naked eye, a number of minute depressions, the *gastric crypts,* or *pits,* from which the gastric glands extend into the deeper portions. The crypts are 0.12 to 0.25 mm. in diameter and the longer and deeper ones are near the pyloric portion. Between or bounding the pits, are the *interglandular projections* (*plicæ villosæ*). Each gland consists of *mouth*, *neck* and *fundus*, or *secretory portion*, and is lined by simple epithelial cells.

The *cells* rest upon a *basement membrane*, which, in turn, rests upon the *tunica propria*. The latter forms the core of the interglandular projections that form the boundaries of the pits. Between the glands, the *tunica propria* consists of narrow bands of the areolar tissue, which contains a great deal of diffuse lymphoid tissue, bundles of smooth muscle fibers from the muscularis mucosæ, and capillaries, both vascular and lymphatic, in great numbers. In places, the lymphoid tissue is collected into solitary nodules that are lens-shaped, and are called the *lenticular nodules*. These are numerous in the pyloric end. The mucosa is bounded externally by the *muscularis mucosæ*, which consists of two layers of smooth muscle fibers, arranged as *inner circular* and *outer longitudinal layers*.

In the *cardiac* and *fundal* portions, the secretory portions of the glands are chiefly of the *simple tubular variety*. The mouth is short, with the neck and fundus of about the same length. In the *neck* and *fundus*, are found two varieties of low columnar cells, the *chief*, *peptic*, or *adelomorphous* cells, and the large *delomorphous*, *acid*, or *oxyntic* cells.

The *surface*, or *true lining cells* of the stomach are tall and narrow elements that line the mouths of the glands, the gastric pits and cover the interglandular projection, or parts intervening between the pits. In the resting stage the basal part contains the nucleus and the cytoplasm is granular; the distal cytoplasm is clear and stains lightly. They are mainly goblet cells and secrete a mucous substance that is probably of a protective nature. Cuticular borders are not prominent and terminal bars are to be found at their distal extremities. These cells form a broad band of palely stained protoplasm in which the basally placed, darkly staining nuclei form a row of closely placed bodies. The lateral boundaries of the cells are not distinct, but the nucleus of each indicates the breadth of the cell. Altogether they give a feather-like appearance to the interglandular projections.

The *peptic cells* are low columnar, or pyramidal elements and are more numerous in the fundi than the necks of the glands. The nucleus is usually circular or oval and contains considerable chromatin. The granular cytoplasm has an affinity for hematoxylin and appears bluish when characteristically stained. During the resting stage the cells become so swollen as to occlude the lumen of the gland. The granules increase in number in the distal portion of the cell, forming a broad zone. These are *zymogen granules* and are derived from the *prozymogen granules* that occupy the basal portion of the cell. These prozymogen granules are in the form of

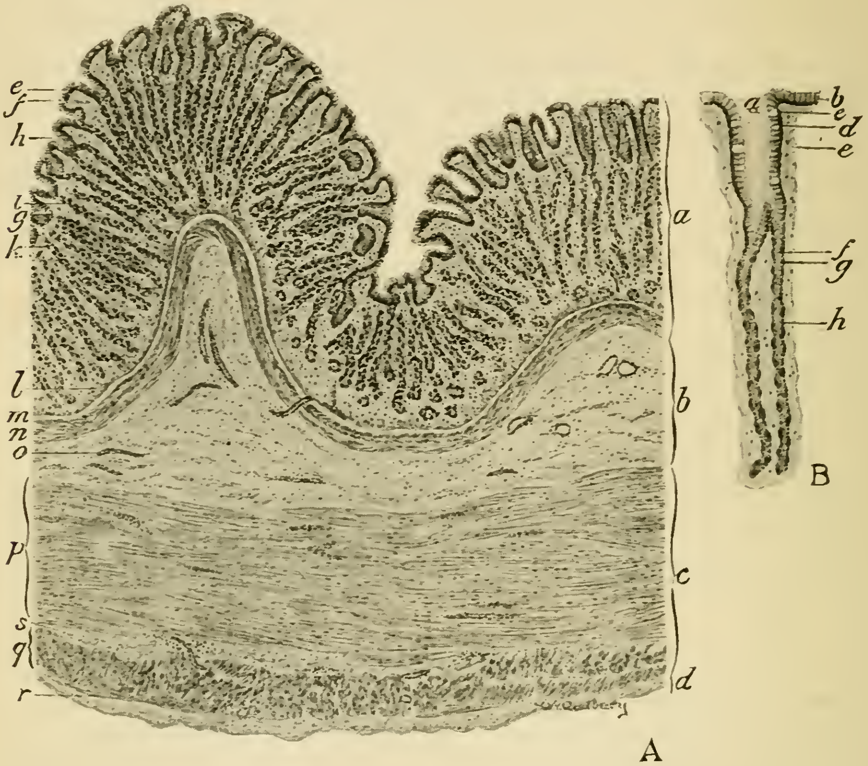


FIG. 157.—CROSS-SECTION OF SEGMENT OF STOMACH.

A, Cardiac Region—*a*, mucous coat; *b*, submucous coat; *c*, muscular coat; *d*, fibrous coat; *e*, epithelium; *f*, interglandular projection; *g*, basement membrane; *h*, gastric pit; *i*, neck of gland; *k*, acid cell; *l*, tunica propria; *m*, *n*, layers of muscularis mucosæ; *o*, submucosa; *p*, circular layer of muscular coat; *q*, longitudinal layer of muscular coat; *r*, oblique layer of muscular coat; *s*, white fibrous tissue layer containing the nerve plexus of Auerbach. B, Gland of Cardiac Region of Stomach—*a*, gastric pit; *b*, columnar epithelium; *c*, goblet cell; *d*, basement membrane; *e*, tunica propria of interglandular projection; *f*, neck of gland; *g*, acid cell; *h*, peptic cell.

small rods and are so placed as to give a striated appearance to the basal part of the cell. These are said to respond readily to toluidin blue or iron hematoxylin. After secretion these cells are greatly reduced in size and are less granular.

The *acid* or *oxyntic cells* are readily distinguished from the others by their size, shape, and affinity for acid stains. They are very large, oval, or triangular elements, most numerous in the *necks*, but also scattered in the *fundus*. They are found *along the wall* of the tubule, and usually beneath the peptic cell, hence the term *parietal*, or *wall*, cell. The nucleus is quite large (there may be two) and centrally located.

These cells are most numerous in the neck of the glands where they are more oval in shape. In the fundus of the gland they are somewhat triangular in form while in the intermediate part of the gland tubule they are said to be sort of wedge-shaped, or pyramidal in outline. The homogeneous, or finely granular cytoplasm contains an elaborate, basket-like system of *secretory canals* that carry the secretion of these cells to the lumen of the tubule. This canalicular system can be outlined by the silver. nitrate method.

The appearance of the parietal cells alters with its stages of rest and activity. During fasting the cells are much smaller and more angular in outline, and may leave their position against the wall of the tubule. During digestion these cells increase greatly in size.

Although these are called the acid cells and are supposed to secrete the hydrochloric acid of the gastric juice this seems improbable as the reaction of the cytoplasm is neutral or alkaline and contains chiefly chlorids. It is thought that an organic chlorid is formed by the cells and when this is passed to the lumen of the gland the hydrochloric acid is liberated. The recent work of Hammett leads him to believe that hydrochloric acid is present in the parietal cells.

In some animals the parietal cells are placed in special depressions of the basement membrane and communicate with the gland proper by only a narrow opening. In some amphibia the glands of the fundus of the stomach contain only the acid cells; their pepsin-forming cells are apparently located in glands in the esophagus. In birds the main tubules of the glandular stomach are lined only with peptic cells and the acid cells line the secondary, or offshoot tubules alone.

The affinity for acid stains is pronounced. With eosin, they are distinctly red, while with acid fuchsin they are colored a very much deeper red.

In the first portion of the **fundus,** the glands are chiefly of the simple tubular variety. As the **pyloric** end is approached, the branched tubulars begin to increase, so that they form the predominating variety in this end. There is also a marked change in the lining cells. The acid cells become rapidly fewer in number, and, in the pyloric end, are but seldom seen. One can, therefore, be safe in saying that a section containing a number of acid cells is from the **fundus,** or **cardia.**

Around the cardiac orifice is a zone 5 to 40 mm. wide where the special tubulo-alveolar **cardiac glands** are found. The cells of these glands are chiefly of the mucous type; other cells similar to the chief and acid cells of the fundus glands and the peptic cells of the pyloric glands are found. These glands represent retrogressive fundus glands (Bensley). According to Ellenberger and others the true cardiac glands contain acid cells and secrete an *amylolytic ferment.*

In the **pyloric canal** the mucosa is thicker and the glands are of the branched tubular variety. The gastric crypts are deeper, the mouths of the glands are longer and the fundi and necks are comparatively shorter. Into each mouth or crypt a number of secreting tubules pour their secretion and these tubules are all the branches of one duct. The fundal or secreting portions may be coiled. These pyloric glands are said to occupy the pyloric fifth of the stomach, according to Piersol.

The *interglandular projections* are covered and the pits and gland ducts are lined with the same kind of tall, slender columnar and goblet cells seen in the cardiac portion. This variety of cell is more extensive, however, on account of the greater amount of surface covered. The *secreting portions of the glands* present an entirely different appearance than the corresponding portions of the fundal glands. In the first place, they are not straight as in the cardia and fundus; in the second place, the branches of one duct are usually grouped closely together and seem to be distinctly separated from their neighbors by denser tunica propria resembling septa, or tiny capsules; thirdly, the cells are different in form and different in stain reaction than those of the cardia and fundus; lastly, the cells are usually of only one variety and the lumen of the secretory tubules is broader than in the other glands of the stomach.

The *cells* are said to be of the *peptic* variety but they differ from those of the cardia and fundus. Each cell is taller and broader than

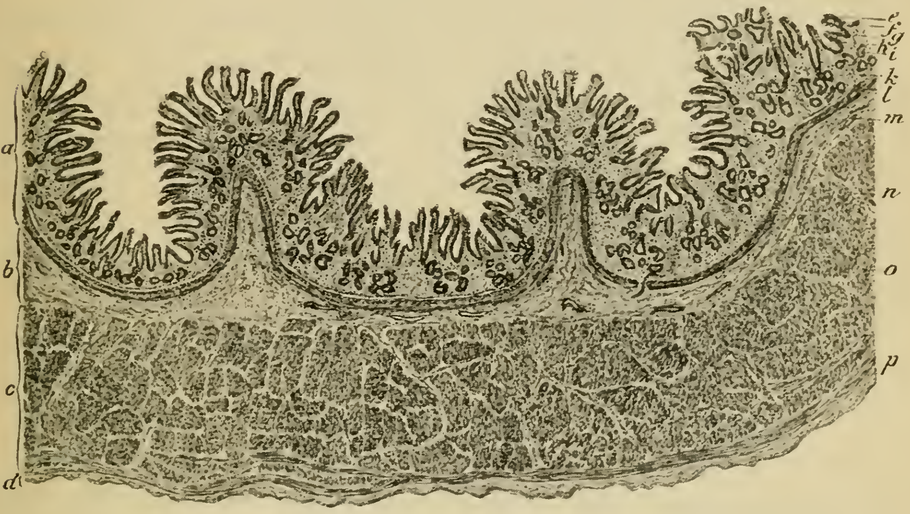


FIG. 158.—LONGITUDINAL SECTION OF SEGMENT OF PYLORIC REGION OF STOMACH. *a*, Mucous coat; *b*, submucous coat; *c*, muscular coat; *d*, fibrous coat; *e*, interglandular projection; *f*, epithelium; *g*, basement membrane; *h*, gastric pit; *i*, pyloric glands; *k*, tunica propria; *l*, muscularis mucosæ; *m*, blood-vessel; *n*, connective tissue in muscular coat; *o*, inner circular layer of muscle; *p*, outer longitudinal layer of muscle.

the ordinary peptic cell and represents a distinct columnar element. They are sharply delimited and differentiated from the cells of the ducts and interglandular projections. The cytoplasm is clear and responds only faintly to the ordinary stains. In the resting stage the cytoplasm is finely granular. The oval nucleus stains readily and occupies a basal location. As the *pyloro-duodenal* junction is reached, the glands become shorter and less numerous, and some may even extend into the submucosa. Intestinal crypts have been found in the stomach. The *interglandular projections* become longer, and resemble, somewhat, the villi of the small intestine but they are not true villi. The pyloric glands may extend from 6 to 14 cm. from the pyloro-duodenal junction.

The mucosa and submucosa are thrown into large, longitudinal folds, the *rugæ*, in the empty contracted stomach. These folds and glands increase greatly the absorptive and secretory surfaces. As the stomach fills these folds become reduced in size and when the stomach is fully distended they are gone. This provision permits of great distension of the organ without injury to the mucosa.

In addition to these glands *crypts of Lieberkühn* have been described in the stomach. These crypts are more numerous in the transition zone (between fundus to pyloric canal), although some have been found scattered in other parts. These resemble the glands of the mucosa of the small intestine; they are simple tubular in form and are lined with simple columnar cells with striated borders and occasionally goblet cells are seen. In the fundi of these glands cells of Paneth are said to be present.

The **submucous coat** consists of areolar tissue. The fibers and bundles are usually coarser than those found in the tunica propria and the meshes formed by these bundles are also larger. This is because the larger blood-vessels and lymphatics are here and the submucosa might readily be called the *vascular coat.* This coat stains lightly because diffuse lymphoid tissue is absent. In this coat is located the submucous plexus of nerves that supplies the muscularis mucosæ and the epithelium of the organ. The submucosa forms a loose distensible coat connecting the muscular and mucous coats and forms the central portion of the rugous folds.

The **muscular coat** consists of smooth muscle tissue arranged in *three layers.* Of these the *inner* is *oblique.* These fibers are continuous with the circular fibers of the left side of the esophagus but they do not form a complete layer. The *middle, circular fibers* form a complete layer and are continuous with the circular fibers of the esophagus. The circular fibers form ring-like masses that start at the fundus becoming at first larger and then smaller as the pylorus is approached. At the pyloric orifice they form a very thick ring called the *sphincter pylori muscle.* The *outer, longitudinal layer* is continuous with the corresponding layer of the esophagus.

These fibers radiate from the cardiac orifice and are most numerous along the curvatures. Although they form only a thin layer on the surface they become increased in number toward the pylorus and become continuous with the longitudnal layer of the intestine. Between the circular and longitudinal layers is the myenteric plexus of nerves for this coat.

The **external,** or **fibroserous coat,** consists of a layer of the *peritoneum*, a serous membrane. This consists, externally, of a single layer of endothelial cells resting upon the fibroelastic subendothelial tissue. It invests all but a very small part of the stomach. At the curvatures it continues away from the organ forming the omenta and it is at these regions that the vessels gain access to the stomach. Beneath this is a thin layer of areolar tissue that constitutes the *fibrous coat.* Some of its fibers pass in between the bundles of muscle fibers of the longitudinal layer and blend with the perimysial sheaths.

The *blood-vessels, lymphatics* and *nerves* will be considered with those of the intestinal tract.

SMALL INTESTINE

The **intestinal tract** consists of two main portions, the **small** and **large intestines.** These each have their subdivisions, which usually differ from one another.

The **small intestine** is divided into **duodenum, jejunum** and **ileum.** They all have the same general structure. This will first be described, and then the differences studied.

There are four coats, *mucosa, submucosa, muscularis* and *fibrosa,* or *serosa.*

The **mucosa** has four layers, *epithelium, basement membrane, tunica propria* and *muscularis mucosæ.* As is the case with the mucosa of the stomach, the epithelium is evaginated in the form of an immense number of tiny glands that are all of the simple tubular variety. The tunica propria and epithelium between the glands are invaginated into the lumen of the intestine in the form of simple, finger-like projections, the villi, that resemble the interglandular projections of the stomach but are a little different in structure and entirely different in function. Through the formation of the glands and plicæ circulares, to be described later, the secretory surface of the tubular intestine is enormously increased. Through the formation of the villi and the plicæ circulares the absorptive surface is also enormously increased.

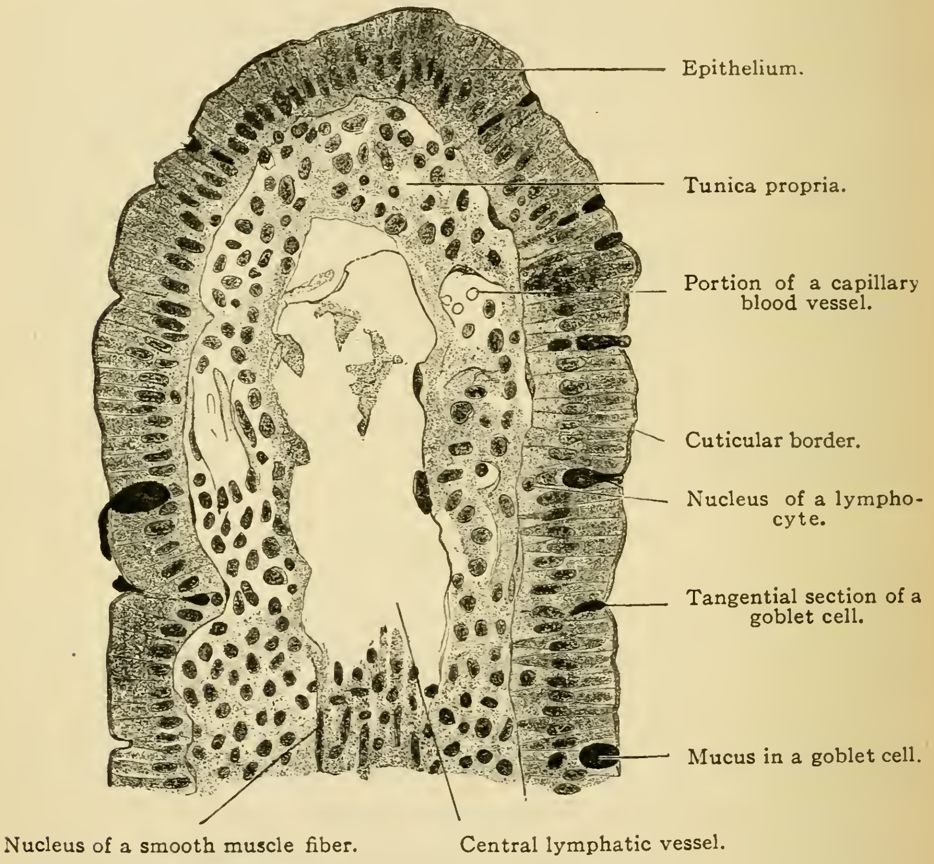

Epithelium.
Tunica propria.
Portion of a capillary blood vessel.
Cuticular border.
Nucleus of a lymphocyte.
Tangential section of a goblet cell.
Mucus in a goblet cell.
Nucleus of a smooth muscle fiber.
Central lymphatic vessel.

Fig. 159.—Longitudinal Section through the Apex of the Villus of a Dog. × 360.

The goblet cells contain less mucus as they approach the summit of the villus.

The *epithelial cells* are columnar in type but vary in structure, those covering the villi differing from those that line the glands. These cells rest upon a thin basement membrane, of a reticular nature, which is supported by the tunica propria. The basement membrane like the epithelial cells has a very sinuous course passing in a continuous manner over the villi and down into the glands.

The *tunica propria* consists of areolar tissue. This fills in the space between the glands and the muscularis mucosæ and forms the core of the villi. It contains a great deal of diffuse lymphoid tissue and the amount varies at different times as the leukocytes come and go. Occasionally Peyer's patches project through the muscularis mucosæ into the mucosa. The abundance of the leukocytes gives tunica propria a dark appearance and hides the areolar tissue. In addition vascular and lymphatic capillaries are very numerous. The nerves from the submucous plexus pass through the tunica propria to their terminations.

The *muscularis mucosæ* consists of smooth muscle tissue arranged into two layers. The *inner layer* consists of circularly arranged fibers and the *outer* of longitudinally directed fibers. It runs an unbroken course usually but in the ileum it may be broken in places by the nodules of a Peyer's patch that is invading the mucosa. The muscle fibers found in the villi are said to be derived from the muscularis mucosæ.

The *intestinal crypts*, or *glands of Lieberkühn* are of the simple tubular variety and involve only the epithelium, basement membrane and tunica propria. These are evaginations of the epithelium and basement membrane that measure 0.2 to 0.3 mm. in depth and extend in a straight course almost to the muscularis mucosæ. The tunica propria that surrounds them and separates one from the other is filled with diffuse lymphoid tissue.

Lining the mouths of the glands and then continuing over the villi are *goblet cells* in various stages of secretion. When these cells have discharged their secretion they are tall columnar elements with cytoplasm that stains fairly darkly; when they are full of secretion they are goblet-shaped and stain very lightly. A cuticular border is distinct. In the necks and parts of the fundi of the glands the cells are of the *simple columnar* type. The cytoplasm of these cells is slightly granular and contains no mucin or fat. A cuticular border is not well developed. They are supposed to be indifferent cells which by mitosis produce daughter cells that may become differentiated into the goblet cells of the neck and villus or the glandular cells in the fundus of the glands. The remaining portion of the fundus of each gland is lined by these simple columnar cells but in the bottom of the fundus are the *cells of Paneth.* These are low columnar, or pyramidal elements in which the cytoplasm is coarsely granular; in some of the cells these granules respond to the plasmatic stains and in others to the nuclear stains. These are no doubt secretion granules in the various stages of elaboration. Other granule cells have recently been described. One of these, the *acidophilic cell,* has fine granules that respond to the acid stains; the other, the *chromaffin cells* (called *yellow cells* by Schmidt) contain fine granules of chromaffin. These cells are found both in the glands and upon the villi and are apparently independent of all of the other cells. Cells resembling the chromaffin cells have been found in the glands of Brunner of the duodenum. Between the various cells of glands and villi leukocytes are frequently seen.

The *villi* are little finger-like projections of the tunica propria covered by the basement membrane and simple columnar cells. They are enormous in number and extend throughout the length of the small intestine and constitute one of its most important characteristics. They increase greatly the absorptive surface of this organ and vary somewhat in number, shape and height in the different divisions of the intestine. The base of the villus is at the level of the mouths of the glands and its tunica propria core is directly continuous with the tunica propria that lies between the glands. The tip of the villus extends into the lumen of the intestine.

Each villus is from 0.2 to 1 mm. in height. The center consists of tunica propria that consists of delicate areolar tissue containing a great deal of diffuse lymphoid tissue. Although the amount of this is constantly variable there is usually enough present to hide the areolar tissue and the other structures. In addition there are numerous blood capillaries, smooth muscle fibers and a dilated lymph capillary in the center called a *lacteal.* The smooth muscle fibers are longitudinally arranged around the lacteal and serve to retract the villus. Those fibers near the tip of the villus are attached to the basement membrane, the muscle fibers branching to make this attachment. The *lacteal* is the starting point of the lymphatic vessels of the small intestine. They are simply large lymph capillaries and extend through the villus toward the muscularis mucosæ where they empty into a plexus of lymph vessels. By contraction of the muscle of the villus this structure is shortened and the lacteal pressed upon and emptied. The valve at the end of the lacteal, where it connects with the plexus, prevents regurgitation of the lymph. Occasionally two lacteals may be found in one villus.

The *basement membrane* is a thin reticulated structure that supports the epithelial cells. These cells consist of a single layer of columnar elements that are really goblet cells in different stages of secretion. The discharged cells are narrow columnar cells, the cytoplasm is slightly granular and stains more darkly than in later stages. The nucleus is near the basal extremity of the cell and is usually thicker than the band of cytoplasm. In the resting stage the secretion makes its appearance in the form of fine granules,

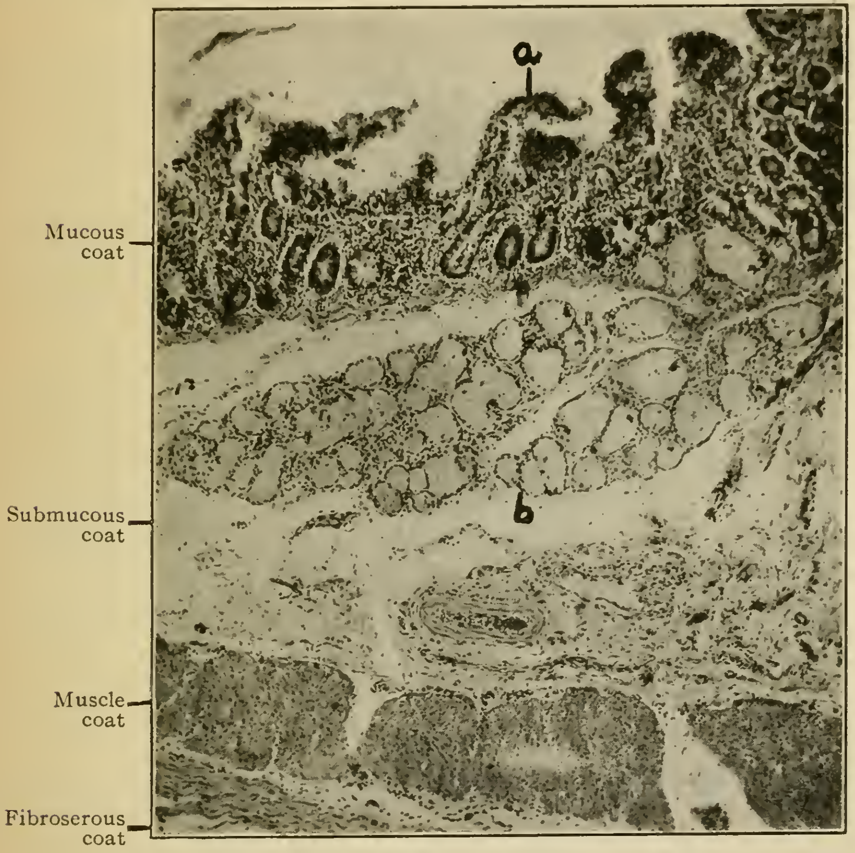


FIG. 160.—LONGITUDINAL SECTION OF THE HUMAN DUODENUM.
a, Villus; *b*, gland of Brunner. (Photograph. Obj. 32 mm., oc. 7.5 X.)

mucinogen, which increase in number and size and respond to special stains. These form a goblet-like mass that crowds the remains of the cytoplasm and the nucleus to the basal part of the cell. When secretion occurs these granules absorb water, swell and run together to form a single droplet of mucin that is discharged into the lumen of the intestine. Each goblet cell possesses a *diplosome* that lies near the middle of the peripheral half of the cell. It is in this region that the mucus is formed.

The villi of the duodenal portion of the small intestine are from 0.2 to 0.5 mm. in height, flat and leaf-like in form and most numerous. In the jejunum they are 0.5 to 0.7 mm. in height, club-shaped. In the ileum they are short and filiform and fewer in number. According to Piersol the number per square millimeter is as follows: Duodenum and jejunum, 24 to 40; ileum 15 to 30. The shape and height are said, by Johnson, to vary according to the state of distension of the intestine.

The mucosa and submucosa are thrown into folds that have a circular direction and are called the *plicæ circulares*, or *valvulæ conniventes*. These extend usually about two-thirds of the way around the bowel though some form complete circles and others form spirals of one or more turns. The spirals may occur individually or in groups of two or three. At their highest points these folds are about 8 mm. in height. They increase the absorptive surface and are permanent, that is no matter how much the bowel is distended within the normal limits these folds are always present. These folds do not begin to appear until a short distance from the pyloric orifice so that the first part of the duodenum is practically smooth. The are quite large just beyond where the conjoined bile and pancreatic ducts open and are nearer one another here. Here they are about the height of a fold apart. In the middle of the jejunum and on they become smaller and more widely separated and ultimately disappear in the lower end of the ileum.

The **duodenum** shows the general characteristics of the small intestine and in addition possesses the *glands of Brunner*, or *duodenal glands* that are characteristic of this division of the small bowel. These are branched tubular structures that are located in the submucosa. Each is small and according to some tubuloalveolar; they are most numerous in the first part of the duodenum and may sometimes break through the muscularis mucosæ and lie partly in the mucosa. The secreting cells stain very lightly giving the idea of a mucous gland. A mucin reaction can be obtained. In the resting condition, just after discharge, the cells appear small, shrunken and granular. During the accumulation of the secretion the cells become larger, swollen and clear. As the ducts leave the gland they run a somewhat irregular course through the submucosa and muscularis mucosæ and mucous coats and empty their secretion at the bases of the villi.

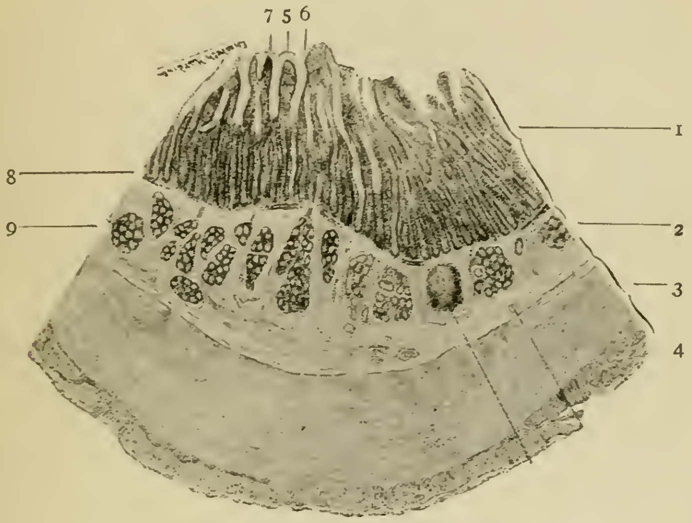


FIG. 161.—CROSS-SECTION OF DUODENUM.

1, Mucous coat; 2, submucous coat; 3, muscular coat; 4, fibrous coat; 5, 6, villi; 7, epithelium of villus; 8, muscularis mucosæ; 9, glands of Brunner.

The **ileal portion** of the small intestine is characterized by the presence of the *agminated nodules*, or *Peyer's patches*. These are a form of lymphoid tissue. Each patch is usually located in the submucosa but at times one may break through the muscularis mucosæ and some of the nodules lie in the mucosa. In the areas over such nodules the glands are usually absent but those at the edges of the nodule may form a circle about it; the villi may also be absent here. Each patch consists of from ten to sixty solitary nodules in one distinct group. Each solitary nodule shows a germinal center and may be surrounded by a partial or complete delicate capsule of white fibrous tissue. Each patch may be 4 cm. in length, 12 to 25 mm. in width and is usually placed opposite to the attachment of the mesentery. They are most numerous in the lower part of the ileum and are closer together here. Some state that they are found also in the jejunum and in the caput coli. There are said to be twenty to thirty of these on the average though as many as

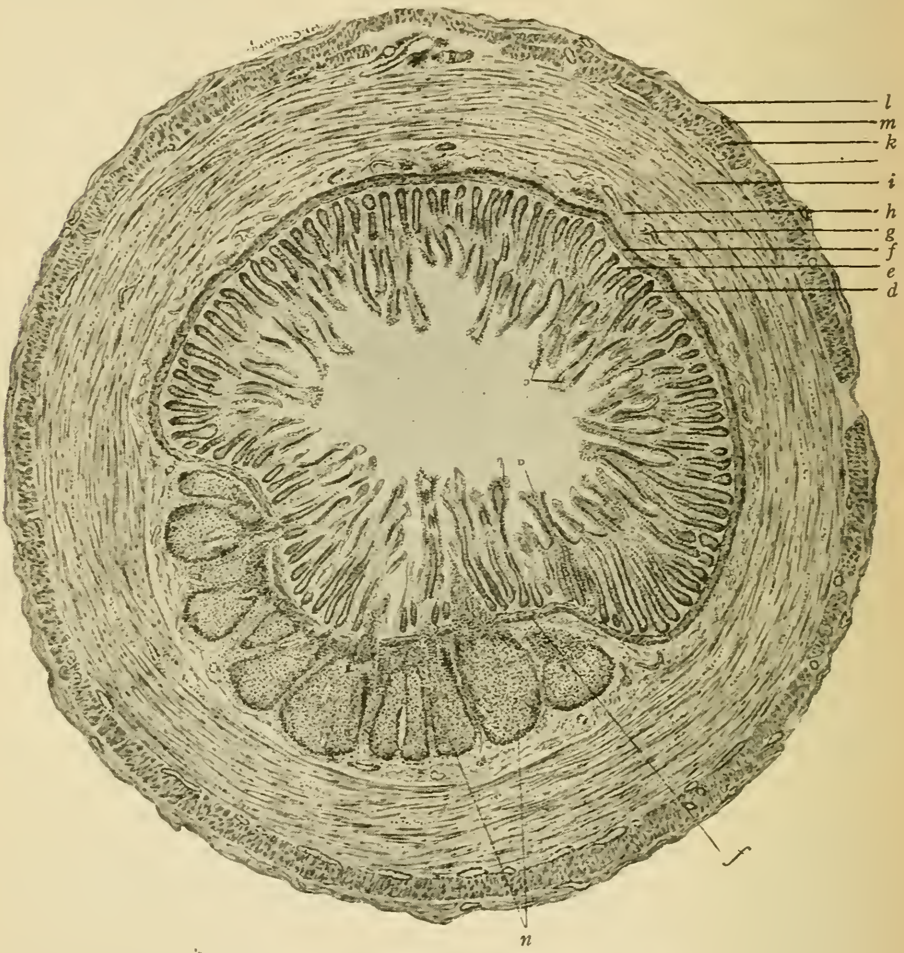


FIG. 162.—CROSS-SECTION OF ILEUM.

a, Villus; *b*, epithelium; *c*, tunica propria of villi; *d*, intestinal gland; *e*, tunica propria; *f*, *f*, muscularis mucosæ; *g*, blood-vessel; *h*, submucosa; *i*, circular muscle layer; *k*, longitudinal muscle layer; *l*, peritoneal layer; *m*, fibrous coat; *n*, nodules of the Peyer's patch.

forty-five have been found in young individuals. They are most marked in the young gradually decrease, in number toward middle age and in the aged may be almost entirely absent. They are the seats of the ulcers in typhoid fever.

Absorption takes place after the ingested food has been acted upon by the various juices of the stomach, small intestine, pancreas and liver. This process of absorption is carried on chiefly by the villi of the small intestine. By the "selective action" of the simple columnar cells covering the villi the *water* and *inorganic salts* are passed through and ultimately reach the blood-vessels. All of the *sugars*, except possibly lactose, are converted into levulose and dextrose and as such are taken into the epithelial cells and transferred to the blood-vessels. In whatever form the carbohydrates are absorbed they never leave these cells except in the form of levulose or dextrose. *Proteins* are converted into peptones by the digestive fluids and as such are absorbed by the epithelial cells of the villi. Native proteins are also absorbed by the mucosa of the large intestine. After absorption the epithelial cells convert these peptones into plasma-albumin and as such are given over to the blood-vessels. Recent investigation seems to point to the fact that the end products of protein digestion are not peptones but less complex bodies, as polypeptids, peptids and amido-acids. It is these simple products that the epithelial cells convert into plasma-albumin and plasma-globulin.

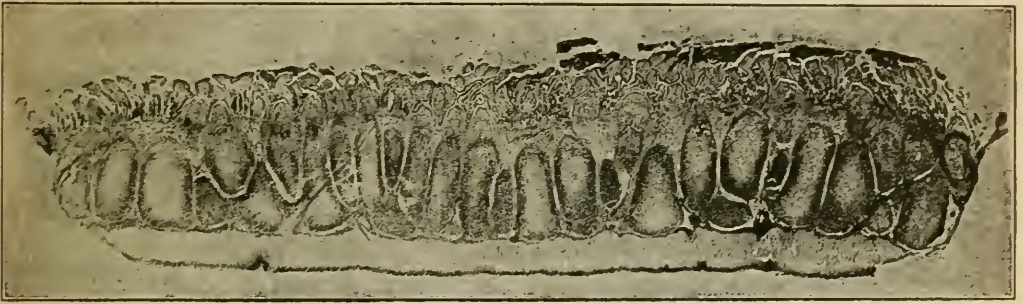


Fig. 163.—An Agminated Nodule of the Ileum of a Cat.
(Photograph. Obj. 48 mm.)

Fats are believed, by some investigators, to be converted into an emulsion during digestion and from this emulsion the fat globules are taken by the epithelial cells and passed through them to the lymph vessels. Others believe that as a result of digestion, fats are converted into soaps and glycerin. The epithelial cells take these and reconstruct fat within the cell bodies and the fat is then passed to the lymph vessels where with the lymph they constitute the chyle.

If parts of the small intestine of animals fed upon rich fatty foods be fixed in osmic acid solutions and sectioned, the fat in the tissues will be seen stained black. In the epithelial cells of the villi the fat droplets are most numerous and larger in the ends of the cells toward the lumen of the bowel. This would seem to indicate the second theory and that the cells had taken these saponification products and reconstructed fat. These droplets are then said to be passed by the epithelial cells into the intercellular spaces of the tunica propria. Here the fat is seen between and in the lymphocytes and also in the lacteals. It is supposed that the lymphocytes assist in the transference and passage of the fat to the lacteals; possibly the endothelial cells of the lacteals assist also in this process. Disintegrating leukocytes with fat in their cytoplasm are found in the lacteals.

The *muscularis mucosæ* consists of two layers of smooth muscle fibers arranged (inner) circularly and (outer) longitudinally. From it bundles are sent up into the villi.

LARGE INTESTINE

This consists of **cecum, colon, rectum** and **appendix.** The structure of all is practically the same.

The **mucosa** contains *simple tubular glands, crypts of Lieberkühn,* which are usually longer, broader and more numerous than those of the small intestine, measuring 0.4 to 0.6 mm. in depth. The cells lining these are *goblet* cells. The tunica propria contains a great deal of diffuse lymphoid tissue that is often collected into solitary nodules that show germinal centers. *Plicæ circulares, villi and cells of Paneth are absent.* Smooth muscle fibers may extend from the muscularis mucosæ to the basement membrane.

The *outer three coats* are like those of the small intestine, except for difference in the muscular coat. The longitudinal fibers are usually thin except where they form the three bands, the *tæniæ coli*, which are about one-sixth shorter than the bowel. These act as a purse string to the intestine, and cause it to be thrown into a number *sacculations*. If the bands be removed, the sacculations disappear. They extend from the cecum to the beginning of the rectum.

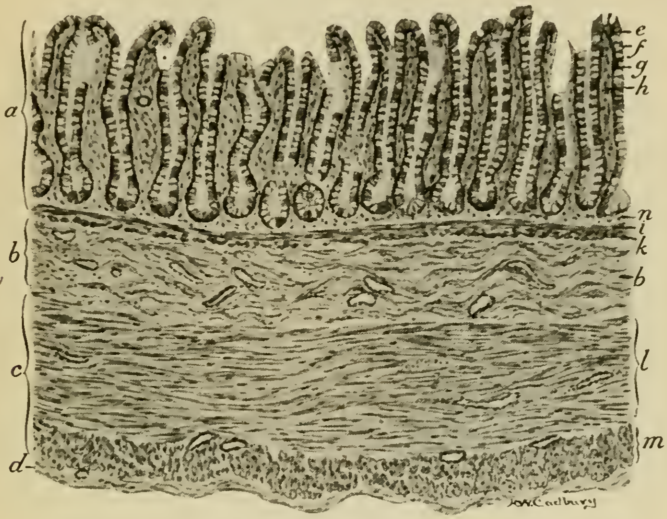


FIG. 164.—CROSS-SECTION OF SEGMENT OF COLON.

a, Mucous coat; *b*, submucous coat; *c*, muscular coat; *d*, fibrous coat; *e*, columnar cell; *f*, goblet cell; *g*, basement membrane; *h*, tunica propria; *i*, inner circular layer of muscularis mucosæ; *k*, outer longitudinal layer of muscularis mucosæ; *l*, inner circular layer of muscular coat; *m*, outer longitudinal layer of muscular coat.

Along the colon and the first part of the rectum the serous coat has the *appendices epiploicæ* attached to it. These are small tabs of adipose tissue that vary in size from a few millimeters to a centimeter or more. Each pad of adipose tissue is covered with peritoneum which is continuous with that of the bowel in the form of a delicate *pedicle*. The fibers in this adipose tissue do not respond well to the ordinary stains and give a hazy picture unlike the ordinary adipose tissue. At times leukocytes, almost in sufficient numbers to constitute diffuse lymphoid tissue, are found in the adipose tissue.

The **rectum** has its mucous and submucous coats formed into folds called the *rectal valves*. These contain a continuation of the muscular coat, by means of which the valves may be protruded into the lumen. At the lower end, the **anus,** *stratified squamous* cells replace the simple columnar, and this marks another *mucocutaneous junction* as in the lips. The circular fibers are more numerous in the rectum and especially at the anal extremity where they form the *internal sphincter muscle*. This is about 4mm. thick.

The **appendix** is a continuation of the cecum. It has the four coats, **mucosa, submucosa, muscularis** and **fibrosa,** or **serosa.**

The **mucosa** is usually irregular, and consists of *simple columnar* epithelial cells that rest upon a *basement membrane*; beneath the latter lies the *tunica propria*, which is bounded by the *muscularis muscosæ*.

In the **mucosa** are a large number of tube-like depressions, the *glands of Lieberkühn*. These possess an equal diameter throughout, and are quite regularly distributed. The cells of the mucosa are the *simple columnar variety*, interspersed with many *goblet* cells. They are quite distinct, and usually possess a *basal* border. The cells in the base of the glands supply the parts higher up, and are consequently the youngest. The glands are about 25,000 (Kelly and Hurdon) in number, and are absent where the solitary nodules are found.

The *tunica propria* consists of a delicate fibro-elastic stroma containing many capillaries, considerable *diffuse lymphoid* tissue and *solitary nodules* (often 300 to 400 in number). The solitary nodules contain germinal centers, and may extend into the submucosa. Immediately over them, the glands are usually absent.

The *muscularis mucosa* is not always present. It consists of smooth muscle fibers forming a thin band separating the mucosa from the submucosa.

The **submucosa** consists of loose white fibrous tissue, and supports the larger blood-vessels. In older subjects, it becomes thicker and denser, and passes into the tunica propria.

The **muscular coat** is usually separable into two distinct layers, *inner circular* and *outer longitudinal*. The former is the more prominent, and extends to the blind end, where the fibers form a dome-like collection of interlacing fibers. The longitudinal fibers are less prominent than the circular. Both layers are pierced, at intervals, by large vessels. Such an opening, of which one especially exists at the blind end, is called an **hiatus** (Kelly and Hurdon).

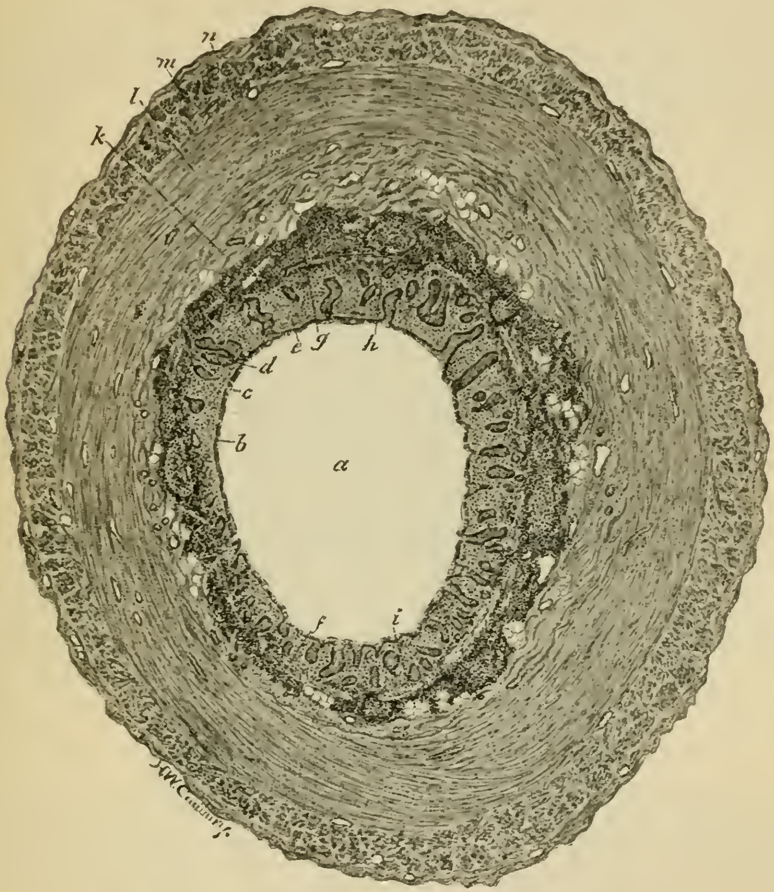


FIG. 165.—CROSS-SECTION OF HUMAN APPENDIX.

a, Lumen; *b*, epithelium; *c*, basement membrane; *d*, glands; *e*, tunica propria; *f*, diffuse lymphoid tissue; *g*, muscularis mucosæ; *h*, solitary nodule; *i*, adipose tissue; *k*, submucosa; *l*, circular muscle fibers; *m*, longitudinal muscle fibers; *n*, fibrous coat.

The **serous** coat consists of white fibrous tissue, surrounded by the peritoneum.

The lumen tends to disappear more frequently than supposed; this change occurs during the ages ranging from 20 to 80. The older the individuals, the higher the percentage of occlusions. The glands are gradually destroyed by the thickening of the submucosa, this process beginning at the blind extremity and proceeding toward the bowel. Occasionally, in this process of occlusion, quite an abundance of adipose tissue is seen in the submucosa.

The *blood-vessels* of the gastrointestinal tract pass between the layers of the mesenteries, or omenta, to the organs where the large trunks enter the submucous coats. In the case of the *stomach* the vessels enter from along the curvatures and represent branches from the aorta, hepatic and splenic arteries. From their anastomoses along the curvatures main trunks enter the organ and in passing through the muscle coat give off small branches thereto; the main vessels continue into the submucosa where they anastomose freely; from this plexus branches complete the supply to the muscle coat. Other branches pass to the mucous coat; these arterioles are at first coiled and then straight giving off numerous capillary branches that pass between the glands toward the epithelial surface where

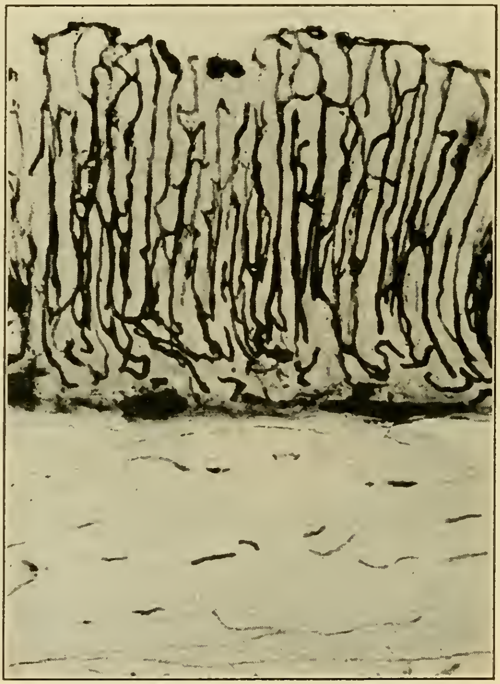


FIG. 166.—SECTION OF THE INJECTED STOMACH OF A GUINEA-PIG. (Photograph. Obj. 16 mm., oc. 75 ×.)

these capillaries form a coarse meshwork around the gastric pits. From this plexus the *venous capillaries* form a fewer number of *larger venules* that after a straight course between the glands unite near the muscularis mucosæ to form a venous plexus. The vessels derived from this plexus pass into the submucous coat where they again anastomose; from this second plexus vessels carry the venous blood to vessels beneath the serous coat and from here to the portal, splenic and superior mesenteric veins.

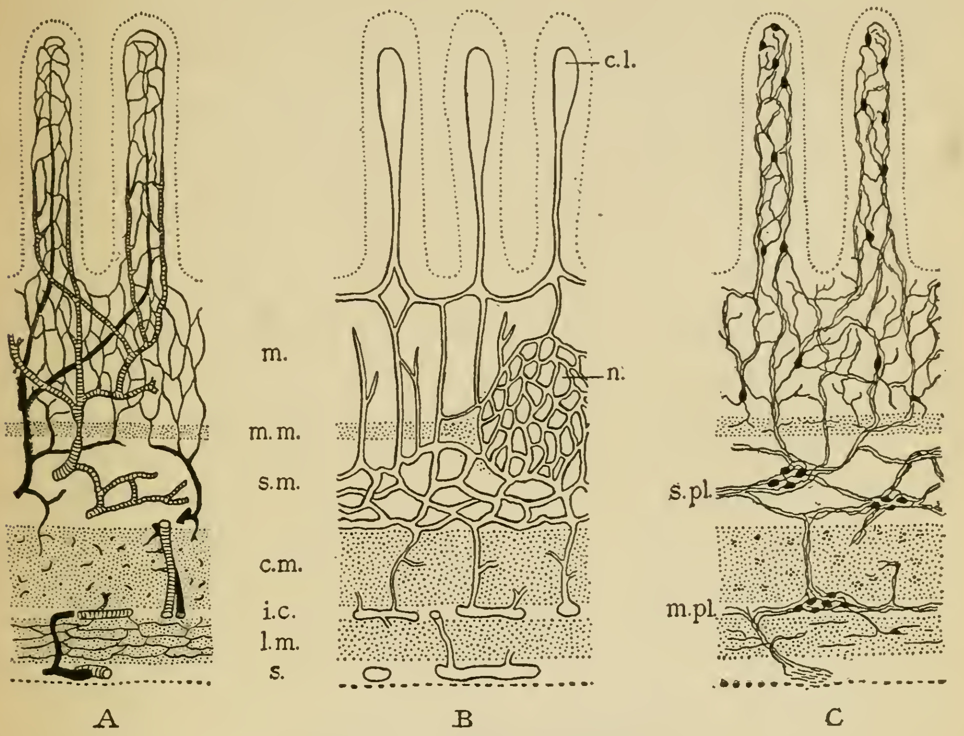


FIG. 167.—(*Lewis and Stöhr.*)

A, Diagram of the blood vessels of the small intestine; the arteries appear as coarse black lines; the capillaries as fine ones, and the veins are shaded (*after Mall*). *B*, Diagram of the lymphatic vessels (*after Mall*). *C*, Diagram of the nerves, based upon Golgi preparations (*after Cajal*). The layers of the intestine are *m*,. mucosa; *m, m.*, muscularis mucosæ; *s.m.*, submucosa; *c.m.*, circular muscle; *i.c.*, intermuscular connective tissue; *l.m.*, longitudinal muscle; *s*, serosa. *c.l.*, central lymphatic. *n.* nodule. *s.pl.*, submucous plexus; *m.pl.*, myenteric plexus.

In the *small intestine* the terminal loops formed by the branches of the superior mesenteric artery, in the mesentery, send branches to the bowel; these branches reach the organ at the mesenteric attachment and each usually divides into two that separate and encircle the bowel, giving off branches in this course and anastomosing after the circuit is completed. These vessels lie under the serous coat. The branches ultimately enter the submucosa, supplying part of the muscular coat on the way, and form a plexus of vessels in the submucosa; branches pass to the muscular and mucous coats. In the mucous coat another plexus is formed and from this numerous capillaries form a meshwork around the glands and individual capillaries extend straight into the villi to their tips, forming a meshwork of capillaries just beneath the basement membrane. The blood continues into *venules* that start near the tips of the villi and after a straight course through the mucosa and submucosa empty into the submucous plexus of veins. This plexus receives also the blood, through venules, from the deeper (glandular) portion of the mucosa and from the muscle coat. From this plexus the efferent vessels have a course corresponding to that of the arteries.

In the *large intestine*, owing to the absence of villi, the vessels are arranged somewhat as in the stomach. The terminal portion of the large bowel differs though. In the anal end of the rectum the vessels of the submucosa are longitudinally arranged; in the anal canal they lie in longitudinal folds of the mucosa. The *veins* of these parts are very large and form the *internal* and *external hemorrhoidal plexuses;* the *internal plexus* has for its efferent vessel the inferior hemorrhoidal vein while the efferent of the *external plexus* is the superior hemorrhoidal vein.

The *nerves* supplying the gastrointestinal tract are the two vagi and the sympathetic system. These nerves form two great plexuses, one in the muscle coat and the other in the submucous coat; at the intersections of the fibers of the plexuses there are sympathetic nerve cells in greater or lesser numbers forming large, or small terminal ganglia.

In the *stomach* the two vagal nerves and branches from the solar sympathetic plexus are the sources of the nerves. These enter the organ and between the circular and longitudinal muscle layers form the *myenteric plexus* (*plexus of Auerbach*) from which fibers supply the muscle fibers of this coat. Other fibers continue into the submucous coat where they form the *submucous plexus* (*plexus of Meissner*) from which branches go to the muscularis mucosæ and to the epithelium of the mucosa.

In the *small intestine* the nerve fibers that form the corresponding plexuses just described are derived from the right vagal nerve and the celiac plexus and superior mesenteric ganglion. These nerves at first follow the larger vessels toward the intestine, anastomosing with one another in this course, and near the intestine leave these vessels and enter the walls of the organ. In the muscle coat the *myenteric plexus* is formed and in the submucous coat the *submucous plexus* is formed. The distribution is the same as in the stomach except the villi are also supplied, some of the fibers going to the muscle fibers in the villi and others to the epithelial covering.

In the *large intestine* the nerve fibers are mainly from the second and third sacral spinal nerves and from the superior, inferior and hypogastric plexuses of the sympathetic system. These nerves form plexuses that are distributed in the foregoing manner.

The *numerous lymph spaces of the stomach* surround the vessels and glands. The lymph capillaries lie in the mucosa well below the surface and between the glands and receive the lymph from the intercellular spaces. At the region of the muscularis mucosæ these capillaries form a plexus the efferents of which pass into the submucosa to form the coarser *submucous plexus*, the vessels of which possess valves. *Another plexus* lies between the muscle coat layers. The efferents from these two plexuses follow the blood-vessels and leave the stomach and carry the lymph to nodes around the stomach.

In the *small intestine* the intercellular lymph spaces are likewise extensive. The first vessels are the *lacteals*, which are closed at the tips of the villi and run a straight course toward the muscularis mucosæ where they all terminate in the *mucous plexus*. At their junctions with the plexus the lacteals have valves. The vessels of the mucous plexus are mostly valveless. The efferents from the mucous plexus carry the *chyle* to plexus of larger vessels in the submucosa; these have valves. A *third plexus* lies between the layers of the muscle coat. Efferents from the submucous and muscular plexuses carry the lymph to the *fourth*, or *subserous plexus*, which is most prominent at the mesenteric attachment. The efferents from the subserous plexus follow the vessels and in the mesentery, at frequent intervals, the chyle is filtered through numerous lymph nodes before it ultimately reaches the common intestinal trunk.

The cells lining the various portions of the alimentary tract are as follows:

Lips		Stratified squamous.
Mouth		Stratified squamous.
Tongue		Stratified squamous.
Pharynx		Stratified squamous
Esophagus		Stratified squamous
Stomach	Cardiac end	Acid cells. Peptic cells. Tall columnar. Goblet cells (a few).
	Pyloric end	Peptic cells. Tall columnar Goblet cells.
Small intestine		Simple columnar. Goblet cells.
Large intestine		Goblet cells. Simple columnar.
Anus		Stratified squamous.

The differences between the small and large intestines are as follows:

	Small.	Large.
Glands.	Long and narrow.	Broad.
Cells.	Chiefly glandular.	Chiefly goblet.
Villi.	Present.	Absent.
Plicæ.	Present.	Absent.
Brunner's glands	Present.	Absent.
Peyer's patches.	Present.	Absent.
Longitudinal bands.	Absent.	Present.
Sacculations.	Absent	Present.

CHAPTER X

THE DIGESTIVE GLANDS

The **digestive glands** are the **liver,** and **salivary glands,** the **parotid, pancreas, sublingual** and **submaxillary.**

LIVER

The **liver,** the largest gland in the body, is *compound tubular* in structure. In the child at birth it represents one-eighteenth to one-twentieth of the body weight, while in the adult it represents about one-fortieth, weighing from 48 to 58 ounces in the male and 45 to 50 ounces in the female. It is surrounded by a sheath of white fibrous tissue, the *capsule of Glisson,* which is covered by peritoneum. On the under surface of the organ, the capsule follows the blood-vessels at the *portal* or *transverse fissure* into the gland, and forms the *interlobular connective tissue* and *intralobular reticulum.* Folds and bands form the various *ligaments, suspensory, coronary* and *lateral.* The *round ligament* is formed by the persistent, closed umbilical vein.

The **liver** is divided into **lobes** and **lobules,** of which the latter represent the **units.** A description of a lobule will suffice for that of the whole liver.

Each **lobule** is about 1 mm. in diameter and Mall states that there are about 480,000 in the liver. Each consists of a collection of **anastomosing** and **radiating chains** of **hepatic cells,** the **tubules,** that start from the **central,** or **intralobular vein,** which represents a large sinusoid. These **chains** are separated from one another by *reticulum,* which supports the cells and the **intralobular blood capillaries**; these capillaries are of the sinusoidal variety; that is, the endothelium is attached to the epithelium of the tubules. As a result the material for secretion is transferred directly from the blood to the liver cells and the internal secretion is transferred directly from the cells to the blood without the intervention of the lymph or lymph vessels. Each **chain** consists of two or three cells side by side, enclosing a small capillary space called the **bile capillary.** Peripherally, the lobules are not separated from one another by connective tissue, except in the *pig* and *camel*. In these animals, the lobules are sharply outlined by bands of connective tissue. This occurs somewhat imperfectly in the human liver under pathologic conditions (*chronic interstitial hepatitis*).

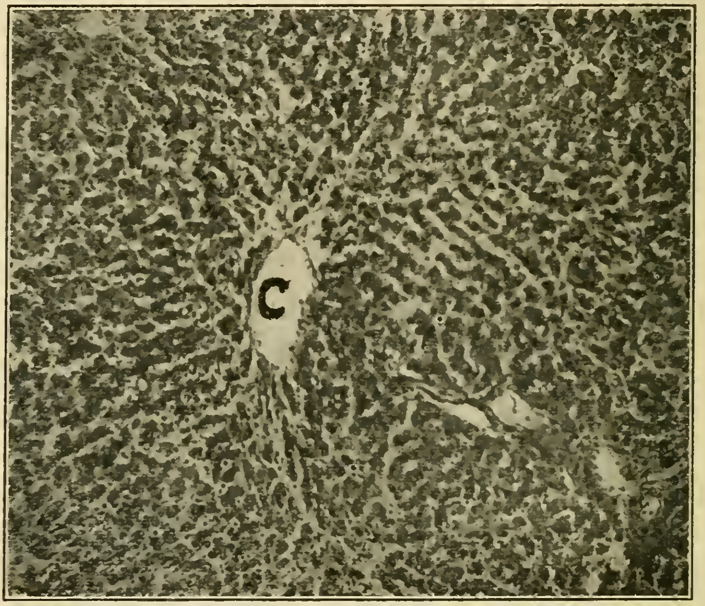


Fig. 168.—Section of a Lobule of the Human Liver. *c*, Central vein. (Photograph. Obj. 16 mm., oc. 5 ×.)

According to Mall, the lobule, as now considered, is not the *structural unit* of the liver; the *structural unit* refers to all the tissue that surrounds each terminal branch of the portal vein.

From the capsule of Glisson large bands or trabeculæ pass into the organ forming the coarse framework of the liver and supporting the larger vessels, ducts and nerves. From the interlobular trabeculæ the *intralobular reticulum* is derived. This is a very delicate meshwork of fine fibrils that support the functionating hepatic cells and the intralobular capillaries. Owing to the fineness of the reticulum, but especially to the extremely close relation of

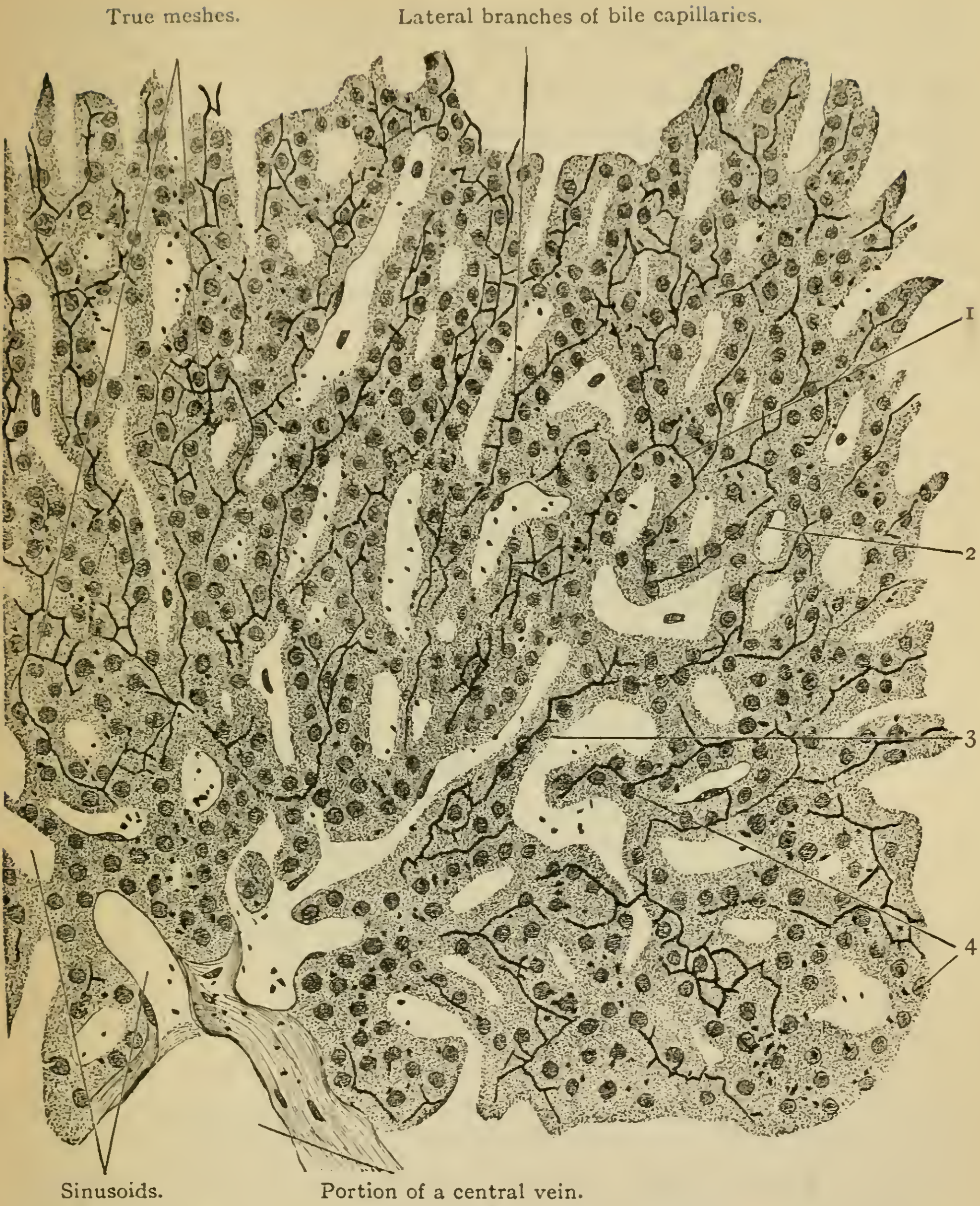

True meshes.
Lateral branches of bile capillaries.
1
2
3
4
Sinusoids.
Portion of a central vein.

FIG. 169.—FROM A CROSS-SECTION OF A HUMAN HEPATIC LOBULE. × 300. (*Lewis and Stöhr.*)

Golgi preparation. The boundaries of the hepatic cells could not be seen. The black dots are precipitates of the silver. 1, Bile capillary in the ansatomosis between two hepatic trabeculæ; 2, nucleus of an endothelial cell of a sinusoid; 3, nucleus of an hepatic cell; 4, nuclei of hepatic cells.

the blood capillaries and the epithelial cells this reticulum is practically invisible or hidden in the ordinary section 10 microns thick. In order to see it it is best to prepare digested preparations. In special preparations stellate cells with two or three processes are seen in the lobules. These are the *cells of Kupfer*. These cells may have one or two nuclei; they are uniformly distributed in the lobule and are said to be phagocytic. In certain regions, at the junctions of several lobules, large masses of the interlobular connective tissue are seen. Upon examination these masses usually contain a branch of the portal vein, hepatic artery, hepatic vein and bile duct and are called the *portal canals*, or *systems*. In pigs and camels the interlobular connective tissue is so abundant as to form a *complete investment of each lobule*, so that in sections, each lobule is separated from its neighbor by a complete wall of white fibrous tissue. The portal canals are present here as above.

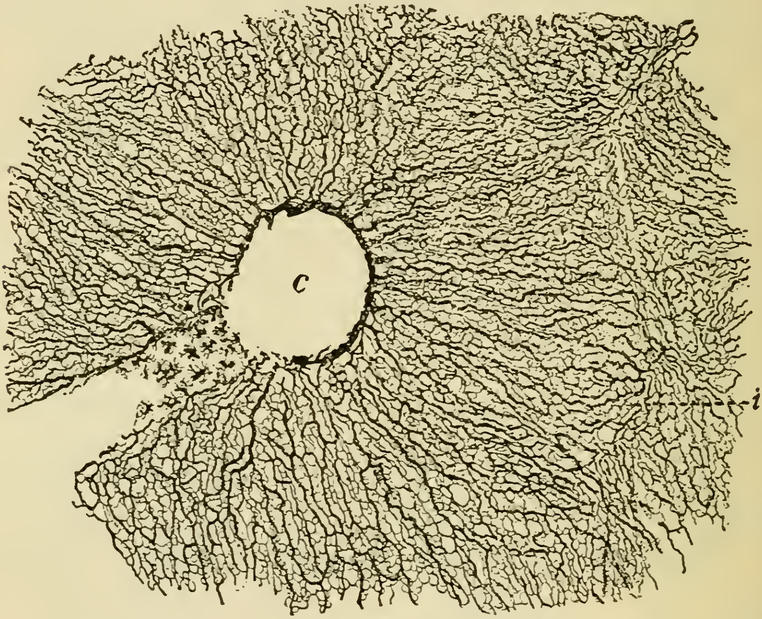


FIG. 170.—RETICULUM OF A LIVER LOBULE.
c, Central vein; *i*, interlobular area. (*Schäfer after Oppel.*)

The *hepatic cells* are large mononuclear masses of protoplasm; occasionally two nuclei may be present in one cell. The cytoplasm is finely granular and an exoplasmic zone may be differentiated. These cells are traversed by a network of fine canals, the *secretory capillaries*, that may communicate, on the one hand, with the bile capillaries between the cells, or on the other hand, with the sinusoidal blood capillaries that surround the epithelial cells. It has been shown that these capillaries extend to the periphery of the hepatic cell and are in such close relation with the sinusoid that the *internal secretions* of the liver (from its glycogenic and urea-forming functions) are readily poured into the blood-vessels.

One of the important functions of the liver is that of forming *glycogen* and storing it until it is required. This substance is in the form of granules of different sizes and the quantity present varies at different times. After meals rich in carbohydrates the glycogen in great in quantity; after meals poor in these substances there is less. After periods of abstinence from carbohydrates glycogen is almost absent from the liver cells. It can readily be demonstrated by means of special stains. It is readily soluble in water and dilute alcohols so that strong alcohol is one of the best fixing agents for its demonstration.

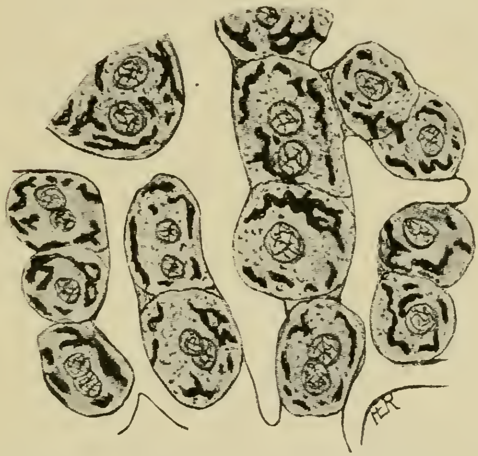


FIG. 171.—INTRACELLULAR CANALICULI OF THE LIVER CELLS COMMUNICATING WITH THE SINUSOID. (*After Schäfer.*)

A few *fat globules* are normal in hepatic cells; these are usually small in size and are distributed mainly in those cells at the periphery of the lobule. After a meal rich in fatty foods the number of fat globules is greatly increased. If large quantities of fat-forming foods are constantly taken then fat is found in abundance in all of the cells. The fat globules usually coalesce to form one or more large droplets and the condition is that of fatty *infiltration*. In *fatty degeneration* of the liver cells the fat globules are numerous but small in the degenerating cells and they do not coalesce. Fat may be readily demonstrated by means of osmic acid solutions or any other special stain for fat.

Pigment granules are often found in hepatic cells especially those near the central vein. This is an iron pigment and is present in the form of small granules that are not numerous in normal conditions. *Mitochondria* are also found in hepatic cells.

The *bile capillaries* that lie between the cells of the tubules or chains, are merely notches in the opposed cells and start blindly near the central vein. These capillaries are small and some consider them true secretory capillaries. They correspond, however, to the lumen of the alveolar or ordinary tubular glands but differ in the fact that they form an anastomosing set of capillaries throughout the entire lobule and do not empty into intralobular ducts as there are no such ducts present in the liver. In some instances three cells form the chains and all participate in the formation of the capillary; in the frog five cells are said to form the tubules and then each one would participate in the formation of this channel. At the periphery of the lobule these capillaries empty into the delicate *interlobular ducts*. The first of these ducts consists of a lining of low columnar epithelial cells that rest upon a delicate basement membrane that is supported by a small amount of areolar tissue, the tunica propria. These soon join larger ducts that lie in the interlobular tissue and receive the bile from a considerable area; these *larger ducts* have *three coats* and are lined with tall columnar cells that rest upon a delicate basement membrane and tunica propria; outside of this is a *muscle coat* consisting of circularly arranged smooth muscle tissue supported by the *fibrous coat*. These ducts are the ones noted in the portal canals. The *largest ducts* have the same general structure and goblet cells may be found in the epithelial layer; the muscle coat is usually thicker and more prominent. The ducts of the right and left lobes join to form the *right* and *left lobar ducts,* respectively, and the structure of these is similar to that of the hepatic and cystic ducts.

The **circulation** of the liver is more peculiar and interesting than that of any other organ in the body. *Two* systems bring blood, yet it leaves through *one.* In other organs, the vessel that supplies the functionating tissue is an **artery**, but here it is a **vein, the portal**

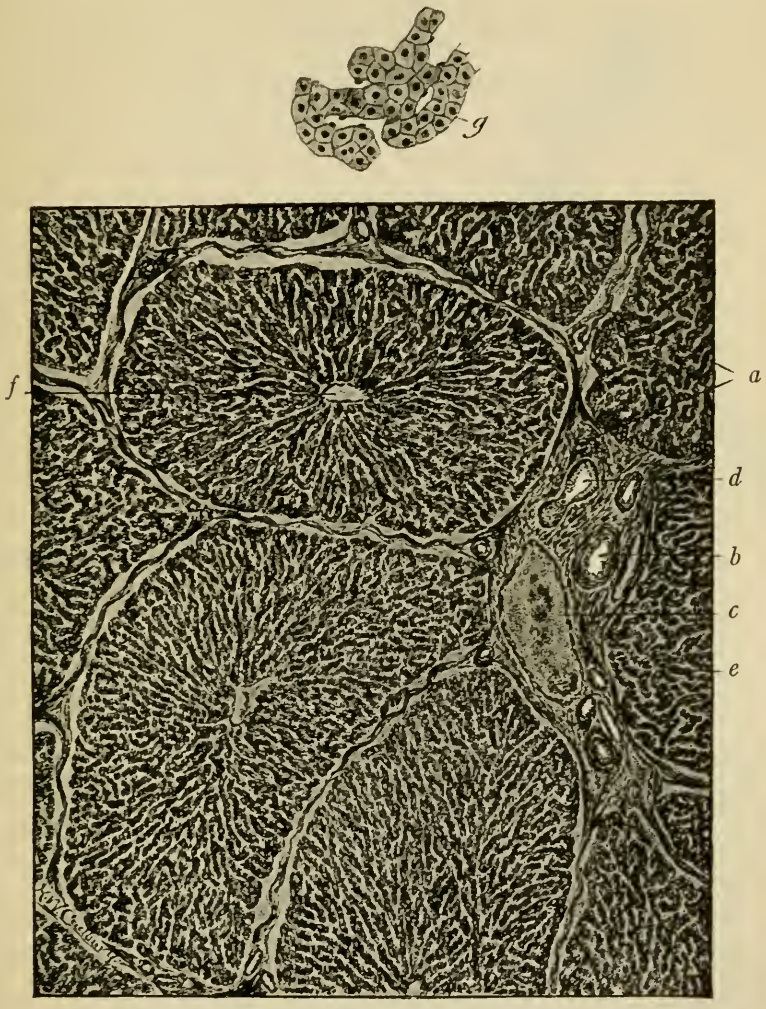


FIG. 172.—LIVER OF PIG.

a, Interlobular connective tissue containing a *portal system* consisting of
{ *b*, Interlobular branch of hepatic artery.
{ *c*, Interlobular branch of portal vein.
{ *d*, Interlobular branch of bile duct.
e, chains of hepatic cells; *f*, central vein; *g*, chain of cells highly magnified.

vein. According to Pearce the portal vein furnishes about 60 per cent. of the blood and the hepatic artery about 30 per cent.

The **portal vein** is made up of the *superior* and *inferior mesenterics, coronary* (stomach) and *splenic veins.* This blood represents the venous return from the gastrointestinal tract. It is richly laden with the altered carbohydrates and digested proteins but contains little fat. It enters *at the portal* or *transverse fissure* of the liver, and forms two main branches, **right** and **left,** one for each main lobe. These rapidly form **interlobular branches** that give rise to the **intralobular capillaries,** found in the lobules, where they converge at the center and empty into the **central,** or **intralobular vein.**

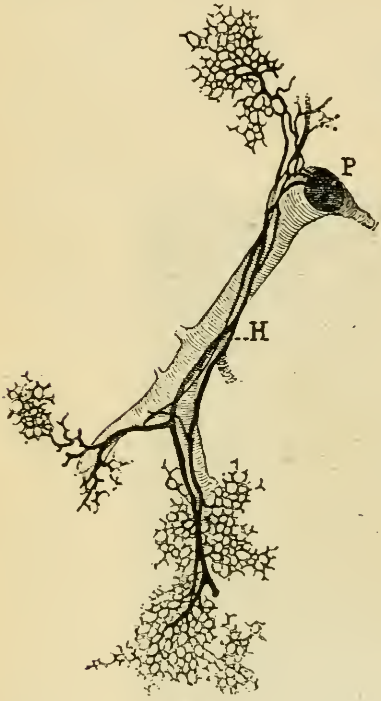


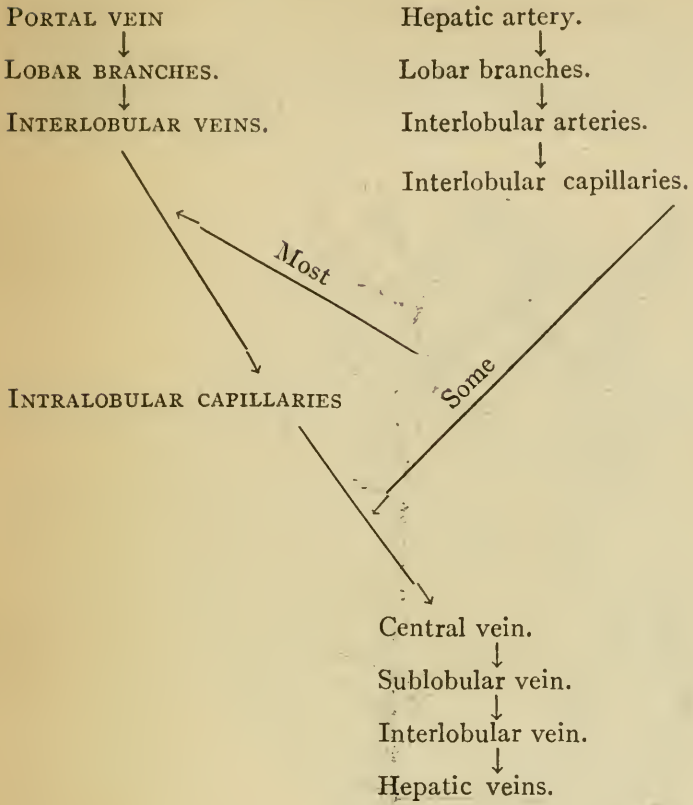
Fig. 173.—Terminal Branches of the Hepatic Artery Forming a Capillary Meshwork.

P, Branch of portal vein; *H*, branch of hepatic artery. (*After Mall.*)

The **hepatic artery** enters the transverse fissure, and forms **lobar** and **interlobular** branches. The *latter rapidly form capillaries that lie in the interlobular connective tissue* and nourish it, and the vessels found here. These are the **interlobular capillaries,** some of which enter the outer third of the lobule and empty into the portal vein capillaries. The *remainder* of the hepatic artery capillaries empty into the interlobular branch of the portal vein, or form small venules that ultimately empty into these.

The blood that has entered the **central vein,** from the *portal vein* and the *hepatic artery,* passes into the **sublobular veins,** which are formed by a union of the centrals, and then into the interlobular branches of the hepatic veins. The **interlobulars** are formed by a union of the **sublobulars,** and these, in turn, unite to form the **hepatic veins** that empty into the blood the *postcava,* or inferior vena cava.

The circulation of the liver might be outlined as follows:


PORTAL VEIN
LOBAR BRANCHES.
INTERLOBULAR VEINS.
Hepatic artery.
Lobar branches.
Interlobular arteries.
Interlobular capillaries.
Most
Some
INTRALOBULAR CAPILLARIES
Central vein.
Sublobular vein.
Interlobular vein.
Hepatic veins.

As the portal vein blood comes into intimate relation with the hepatic cells, the latter remove the products required for nutrition, also the excess of glucose, which is converted into *liver sugar*, or *glycogen*, and, in addition, take out the constituents of the bile; it is now considered the seat of urea formation.

The *lymphatics* are *superficial* and *deep*. The *superficial* drain into either the celiac and hepatic lymph nodes on the one hand, or through the diaphragm into the ventral mediastinal nodes. The *deep* pass out either through the portal fissure to hepatic and celiac nodes, or along the hepatic vein pass through the diaphragm to nodes around the postcava. The blood-vessels are surrounded by lymph spaces that communicate with similar spaces at the periphery of the lobule and in the interlobular connective tissue. Within the lobule lymph spaces are not numerous as the endothelial cells of the sinusoids are attached to the epithelial cells of the hepatic tubules. In the interlobular area the lymph spaces and channels are numerous and the lymph is abundant.

The *sympathetic nerves* form the chief source of enervation of the liver. They lie in the interlobular connective tissue as plexuses, and from these some fibers pass to the bile ducts, and blood-vessels and others penetrate the lobules to pass beneath the cells. Here they are said to end upon the epithelial cells as knobs or fibrils.

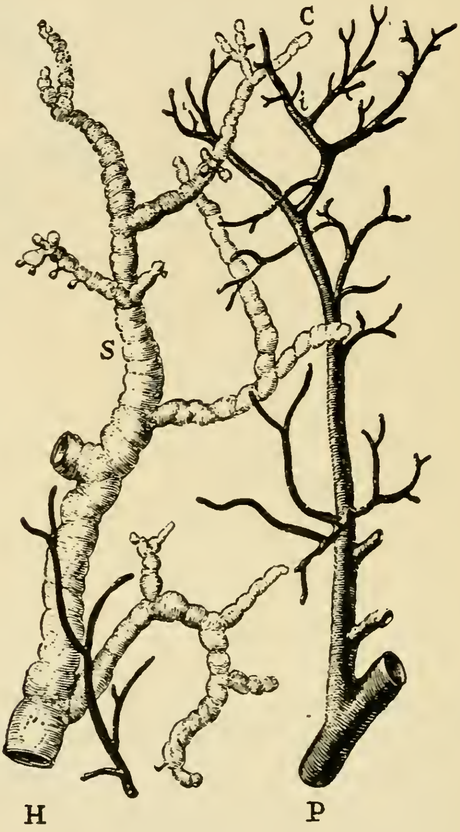


Fig. 174.—Terminal Branches of the Veins of the Liver.

H, Branch of hepatic vein; *P*, branch of the portal vein; *S*, sublobular vein; *C*, central vein; *i*, interlobular branch of the portal vein. (*After Mall.*)

The **excretory apparatus** consists of the **gall-bladder, hepatic cystic** and **common ducts.** They all possess three coats, **mucous, muscular** and **fibrous.**

The **hepatic duct** is about 2.5 to 3 cm. in length and 3 to 4 mm. in diameter; the **cystic duct** is about 3 to 3.75 cm. in length and 3 to 4 mm. in diameter; the **ductus cholidochus** is about 8.5 to 10 cm. in length and to 6 to 7 mm. in diameter. These are alike in structure. The **mucous coat** consists of a single layer of tall columnar and goblet cells that rest upon a *basement membrane* and *tunica propria*. In the latter are seen a number of *tubuloalveolar glands* that open out upon the epithelial surface. Diverticula of the mucosa are also numerous especially in the hepatic duct and even within the liver substance. The **muscle fibers** are quite distinct. They are arranged as *circular*, *longitudinal* and *oblique* layers. The *circular* fibers of the common duct form a *sphincter* at its entrance into the duodenum. This is supported by a rather thick layer of white fibrous tissue constituting the **fibrous coat.**

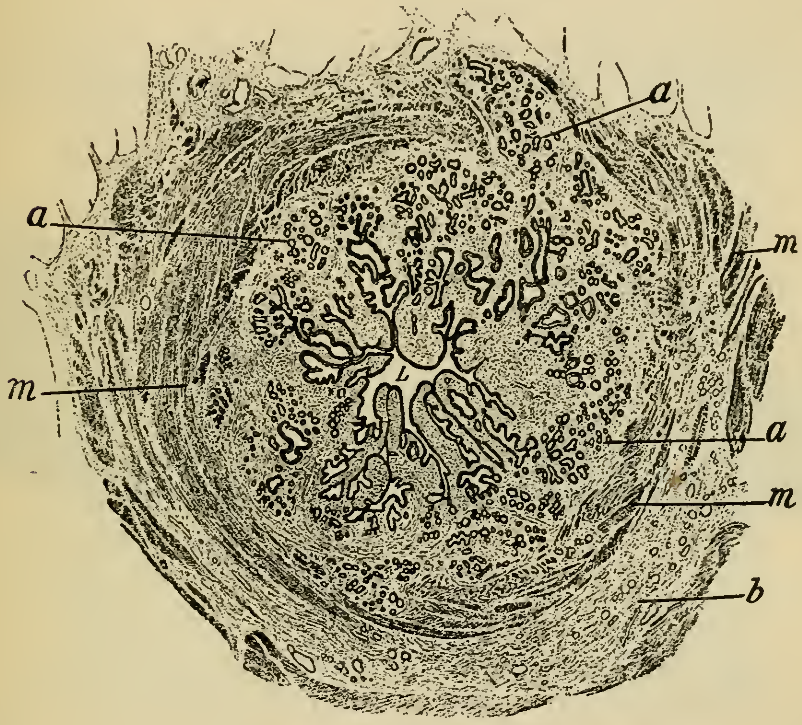


Fig. 175.—Cross-section of the Hepatic Duct.

a, *a*, Tubules of glands; *b*, areolar tissue; *m*, *m*, smooth muscle tissue of muscle coat; *L*, lumen of the duct. (*After v. Ebner.*)

The **mucosa of the gall-bladder** consists of tall columnar and goblet cells, *basement membrane* and fibro-elastic *tunica propria*. The epithelial cells resemble those of the small intestine and secrete mucous. The tunica propria contains a few mucous glands, some diffuse lymphoid tissue and even solitary nodules and some muscle fibers derived from the muscle coat. In the empty and partially distended condition the mucosa is seen formed into rugous folds, which at the neck are permanent.

The **muscle coat** is composed of smooth muscle tissue and a considerable quantity of white fibrous tissue, the latter predominating near the mucous coat. Elastic tissue is also present. The muscle fibers interlace somewhat although most of them are circularly arranged. The **fibrous coat** consists of white fibrous tissue that is attached to and connected with the fibrous tissue of the liver. It is partially invested with the peritoneum.

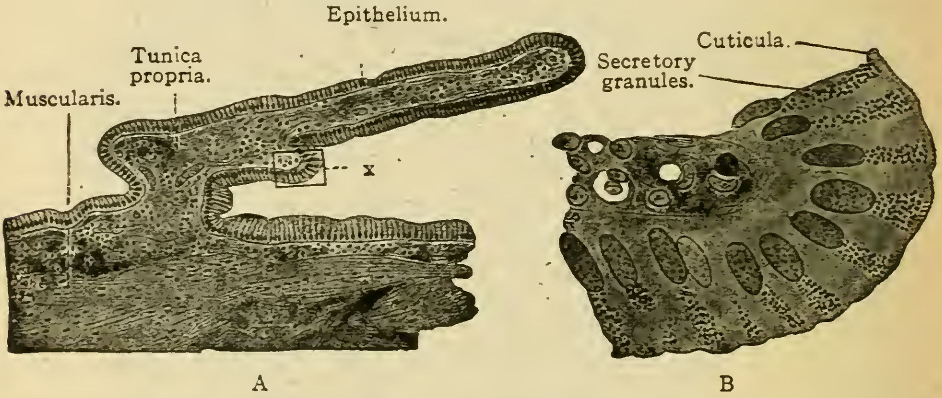


Fig. 176.—From a Section of the Gall-bladder of an Adult, *A*. × 100. *B*, The portion x of *A*. × 560. (*Lewis and Stöhr*.)

The *lymphatics* are connected to those of the liver by the subserous plexus, into which the vessels from the muscular coat empty.

The *nerves* are *sympathetic* and *cerebrospinal*, the *former* passing to the blood-vessels and muscles, and the *latter* ending in the mucosa, near large arteries. Sympathetic ganglia, also, are found in the walls of the gall-bladder and nerve fibers and free sensory organs are found in the epithelial layer.

SALIVARY GLANDS

The **salivary glands** are the **parotid, pancreas** (the abdominal salivary gland), **sublingual** and **submaxillary glands.** In addition, there are a large number of small unnamed glands in the lips, mouth, tongue, pharynx, base of the epiglottis, palate and esophagus.

According to **secretion,** they are divided into **mucous, serous** and **mixed.**

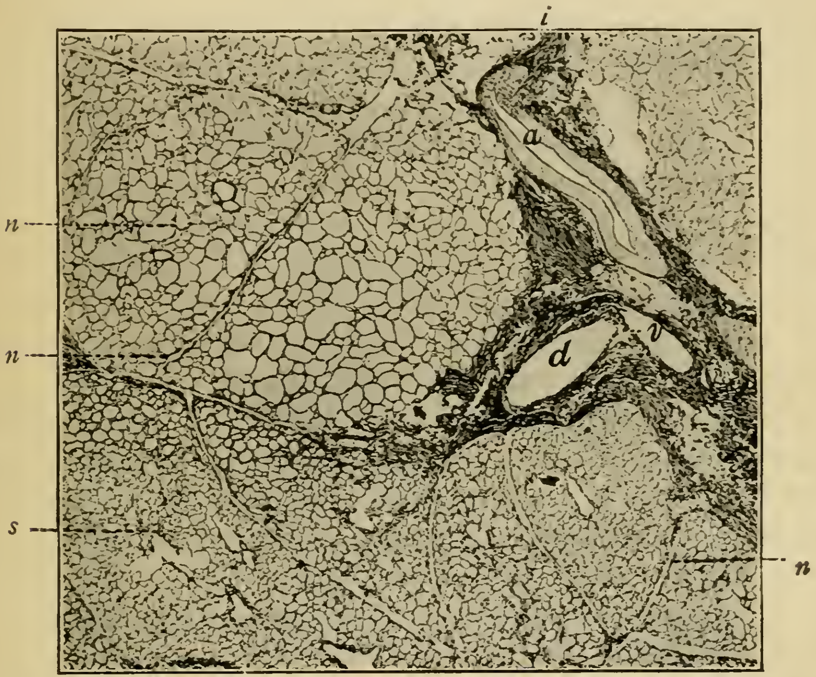


Fig. 177.—Interstitial Tissue of the Human Sublingual Gland. *a*, Artery; *d*, duct; *v*, vein; *i*, interlobular connective tissue; *m*, mucous lobule; *n*, *n*, interlobular septa; *s*, serous lobule. (*J. M. Flint.*)

The **mucous** glands are distinguished by their large *secretory units* that stain lightly. These are the *acini, alveloi* or *tubules,* and they give rise to a thick viscid secretion. Such glands are the small glands of the mouth, pharynx and esophagus. The **sublingual** is almost a pure mucous gland.

Serous glands are those in which the acini stain darkly, owing to the presence of secretory granules in the cytoplasm, which retain the stain. The acini are usually smaller than those of mucous glands

These glands secrete a thin albuminous fluid. Such are the **parotid** and **pancreas.**

The **mixed** glands are those that stain both lightly and darkly, and secrete a mixed fluid, as the **submaxillary** and **sublingual.**

As all of these glands have the same general structure, this will be first considered, and the special points then noted.

Each is surrounded by a **capsule** of white fibrous tissue that limits it from the surrounding organs or tissues. The **capsule** sends in prolongations that divide the gland into **lobes** and **lobules.** The **lobules,** or **structural units,** consist of the *functionating units* that are composed of a single layer of *glandular epithelial cells* (*parenchyma*) supported by a *basement membrane.* External to the basement membrane, is the *interstital,* or *intertubular connective tissue,* which is composed of reticulum, and in which the blood-vessels, nerves and lympathatics are found. It corresponds to the tunica propria of a mucous membrane.

The **secretory units** lead into minute **intermediate,** or **intercalated tubules** that unite to form **intralobular ducts,** which pass into the interlobular connective tissue. Here they unite to form the **interlobular ducts;** these, by union, form the **lobars,** and then the **single excretory duct.** The **intermediate tubules** are lined by *simple squamous* or *low columnar* cells, supported by basement membrane and interstitial tissue; the **interlobular** branches contain *simple columnars,* the **intralobulars** and **interlobars** are lined by *pseudo-stratified columnars,* and the **excretory duct** usually by *stratified columnars.* In the latter duct the muscle coat is distinct.

The *blood-vessels* follow the divisions of the ducts, and form plexuses of capillaries around the secretory units, and in close proximity to the epithelium.

The *nerves* pass down in the same manner, and, after penetrating the basement membrane, end around the cells.

The **parotid gland** is a compound alveolar gland and is divided into lobes and lobules as has been described. It represents the largest oral salivary gland. In each lobule are seen the secreting units, or acini, which are serous in character, the intercalated and intralobular ducts. Each *acinus* consists of a number of small darkly staining cells of a pyramidal shape arranged in a single layer upon the thin basement membrane. In the center of the group of cells is a *lumen*, the size of which depends upon the stage of activity of the gland. The acini are comparatively small. The *basement membrane* contains flattened *basket cells* at the bases of the epithelial cells, and the processes of these basket cells pass between the functionating epithelium. These are supposed to be young secreting cells that replace the older ones as they give out. The *cytoplasm* of the secreting cells is nearly clear and finely granular in the early resting stage; during the latter part the granules increase in number and a small amount of clear cytoplasm and the nucleus occupy the basal portion of the cell. The cell becomes so swollen as to occlude the lumen and as these *zymogen granules* are discharged during the active stage the cells become smaller and the granules nearly all disappear; the clear cytoplasm increases in amount and spreads through the cell. *Prozymogen*, or *mitochondrial filaments* have been demonstrated in the basal portion of the cells. In the cytoplasm and between the cells there is a set of *secretory capillaries*, or *canaliculi*. The acini pass the secretion to the *intercalated tubules* that are lined with squamous cells and these join the *intralobular ducts* that are lined with low columnar elements. These in turn empty into the *interlobular ducts* that lie in the interlobular connective tissue. These are larger in caliber and are lined with columnar cells and possess three coats.

Considerable adipose tissue is found in the interlobular tissue of the parotid gland.

The **parotid duct** is the excretory duct.

The **pancreas** is the other serous gland and is compound alveolar in structure. It is also called the *abdominal salivary gland*. Its general structure is analagous to that of the parotid. The lobules contain the secreting units, or acini that are larger than those of the parotid however. These acini are usually distinct, sharply outlined and stain darkly. Here and there between them are seen the *islands of Langerhans* that will be described later. The cells lining an acinus are of the pyramidal type and the amount of lumen showing will depend upon the stage of secretory activity. These cells rest upon the basement membrane but interposed are the peculiar stellate basket cells that are immature secreting cells, so it is said. During rest these cells show a clear cytoplasm, only a few granules being present near the lumen end. As the secretion is being formed these *zymogen granules* increase in amount, the cell becomes swollen and only a narrow rim of cytoplasm, containing the nucleus, is seen at the basal portion of the cell. The lumen is practically occluded. With the discharge of the secretion the clear cytoplasm increases and spreads through the cell, which is much smaller in size. The nucleus plays an important part in secretion. A *paranucleus* is seen in active *cells*. This is derived from extruded nuclear material and is said to be changed into secretion granules but this is denied by some. In the basal portions of the cells *mitochondrial filamenis* are readily demonstrated. These are said, by some, to give rise to the zymogen granules, but others believe that they are concerned only with the metabolic activities of the cell. Within many of the acini are seen lightly staining flattened elements that are called the *centro-acinar cells*. These are characteristic of the pancreas and represent the

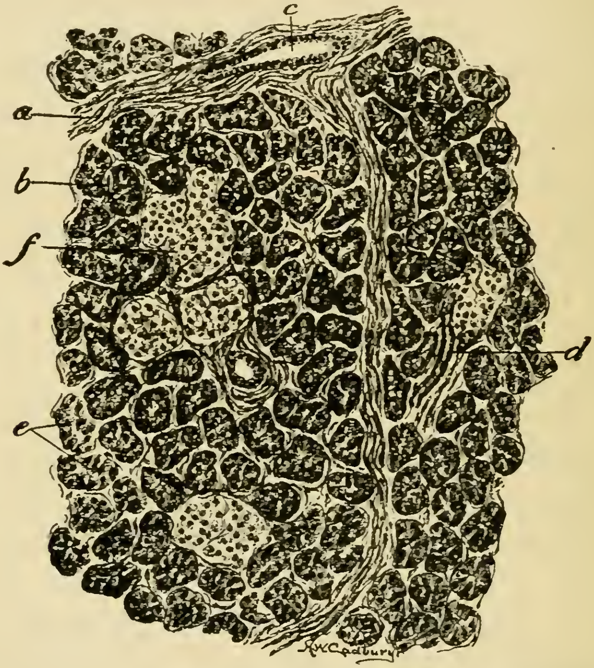


FIG. 178.—SECTION OF HUMAN PANCREAS SHOWING PANCREATIC ISLANDS.
a, Interlobular connective tissue; *b*, capillary; *c*, interlobular duct; *d*, intralobular duct; *c*, cells of acini; *f*, area of Langerhans.

squamous cells of the intercalated tubules invaginated into the acinus. They are separated from the secreting cells by intercellular secretory capillaries.

In addition to the acini numerous groups of lightly staining cells are scattered in the lobules; these are the *pancreatic islands*, or *areas of Langerhans*. These are oval, or circular in outline and each is surrounded by a delicate capsule that sends in trabeculæ that seem to arrange the cells into irregular groups, or cords. The number of cells in an island varies from several to many so that these islands may be microscopic or macroscopic (3 mm.) in size. The cytoplasm of these cells stains lightly and contains some fine eosinophilic granules that are supposed to be of two kinds and therefore form two different kinds of secretion. The blood-vessels are of the sinusoidal type and are in close relation to the cells, forming glomerule-like masses in injected sections. These possess no outlet for the secretion (*enzyme*, or *harmone*) that they form and this is supposed to be passed directly to the blood capillaries.

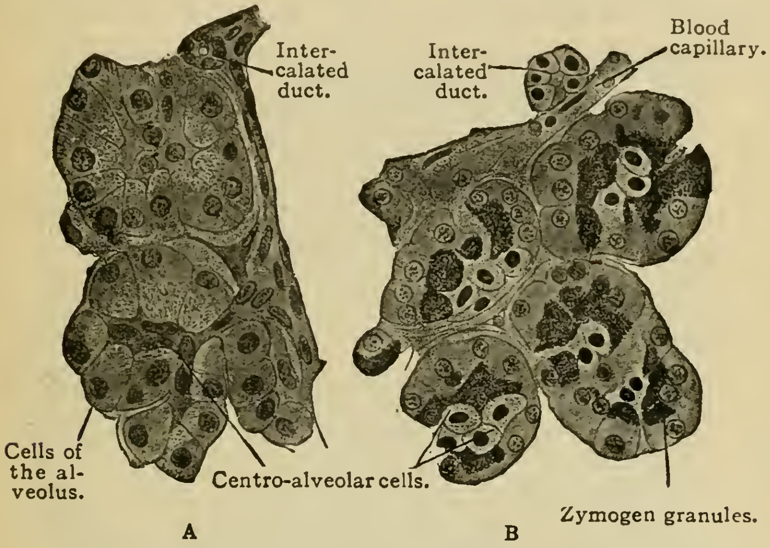


FIG. 179.—FROM SECTIONS OF A HUMAN PANCREAS. × 500. (*Lewis and Stöhr.*) In section *A* the granules are wanting, the centro-alveolar cells are flat and dark; in section *B* the granules are distinct, the centro-alveolar cells are cuboidal and clear.

These islands are most numerous in the splenic end of the pancreas and vary considerably in number. Dole states that they may be increased in size and number by means of secretion and that in long hunger they are also increased; this probably merely represents a normal individual variation. Thompson and others claim that there is a connection or lumen between the islands and acini in reptiles and fishes. This connection does not apparently exist in man as ligation of the pancreatic duct does not affect the islands nor does it interfere with carbohydrate metabolism. If the islands are diseased (in some cases at least) or if the pancreas of an animal be removed diabetes mellitus follows. The areas then, postmortem, show degenerative changes.

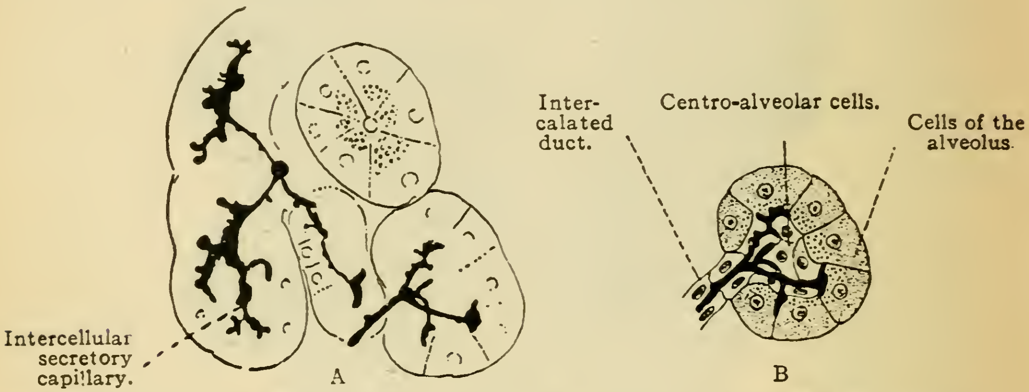


FIG. 180.—*A*, FROM A SECTION OF THE PANCREAS OF AN ADULT MAN. × 320. B, AN INTERPRETATION OF THE RIGHT LOWER PORTION OF *A*. (*Lewis and Stöhr.*)

According to Bensley some of these islands may be found in the interlobular tissues connected with the ducts; some in the lobules connected with the ducts; other in the lobules connected with the ducts and acini; others not connected with the ducts or the acini. Although the acini and the islands seem to have the same origin in the embryo, after their adult stage they are unalterable. They may be stained intravitam by means of neutral red and janus green.

The **excretory duct,** the **duct of Wirsung,** is lined by *simple columnar* cells.

The **submaxillary gland** is a tubuloalveolar gland in structure and a mixed gland in secretion. The mucous tubules may be collected in individual lobules and lobes or they may be mixed with the serous acini. In man it is said that the serous acini are five times as numerous as the mucous tubules. The serous acini resemble in structure those of the preceding glands and the acini are intermediate in size between those of the parotid and pancreas. The mucous tubules are the larger. The cells are of the column variety, are quite large and stain lightly. In the fresh condition the cytoplasm is clear and refractile. In properly fixed tissue the cytoplasm contains a coarse reticulum that is basophilic in reaction and is located mainly in the lumen portion of the cell. The cytoreticulum contains some coarse granules that respond to special mucin stains. During the resting stage these granules increase in number and the cells become larger and have a swollen appearance. When the secretion is to be discharged water from the lymph between the cells passes into the cells, the granules swell and are dissolved and the secretion is discharged. The cell is then smaller. These granules do not show in ordinary preparations as they are so soluble that they must be fixed in certain reagents only. In the full cell the nucleus and a little finely granular cytoplasm are forced against the base of the

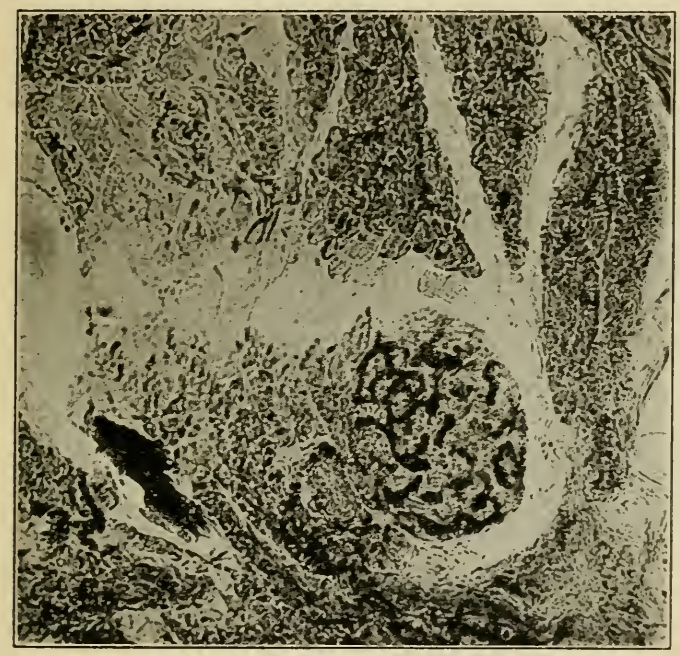


FIG. 181.—AREA OF LANGERHANS OF THE INJECTED PANCREAS OF A GUINEA-PIG. (Photograph. Obj. 16 mm., oc. 7.5 X.)

cell. When the secretion is discharged the nucleus moves away from the base and the cytoplasm spreads towards the distal extremity of the cell. In these tubules of most of the mucous and mixed glands (exceptions are those of the soft palate and base of the tongue) other cells are found between the mucous cells and the basement membrane. These are darkly staining cells and are arranged in the form of crescents and constitute the *crescents of Gianuzi*, or *demilunes of Heidenhain*. These groups are chiefly located at the blind extremity of the mucous tubules and although at times they may reach to the lumen they are usually separated therefrom by the mucous cells. The cytoplasm is quite granular and the nucleus quite chromatic and basally placed. *Intracellular* and *intercellular capillaries* are numerous; the secretion is discharged from the former into the latter and through these gains access to the lumen of the tubule. In this they resemble *true serous cells* and in addition Krause has shown that these cells will discharge sodium indigo sulphate granules just as do the serous cells. Stöhr and others believe these cells to be the resting stages of the mucous cells. The *intralobular ducts* are unusually large and distinct in some animals and often represent a distinguishing characteristic of this gland.

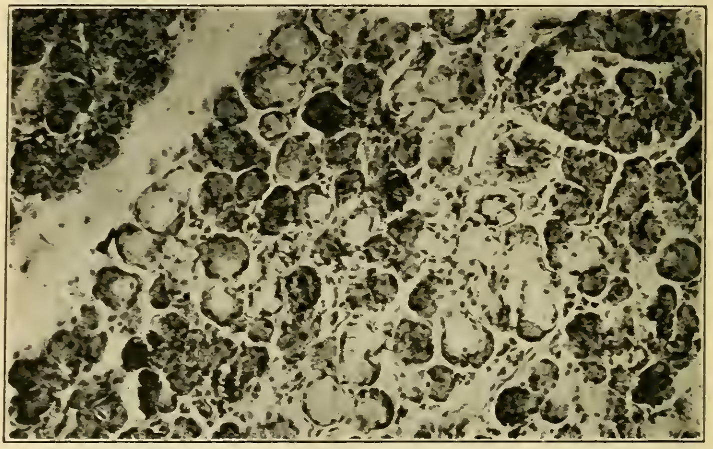


FIG. 182.—SECTION OF THE HUMAN SUBMAXILLARY GLAND SHOWING MUCOUS TUBULES AND SEROUS ACINI.

The lightly stained mucous tubules show demilunes of Heidenhain. (Photograph. Obj. 4 mm., oc. 7.5 X.)

The *excretory duct* is the **submaxillary duct, or duct of Wharton.**

The **sublingual glands** really represent a collection of glands and not an individual gland upon each side in the floor of the oral cavity. Each mass weighs only 3 to 4 grams and so represents the smallest of the salivary glands. It is compound tubular in structure and nearest to the pure mucous glands as it does not contain many serous acini; the serous portion is represented by the *crescents of Gianuzi.* Occasionally sections of serous acini are apparently seen but these are said to represent cross-sections of the tubules, near the blind end, in which the crescents abound.

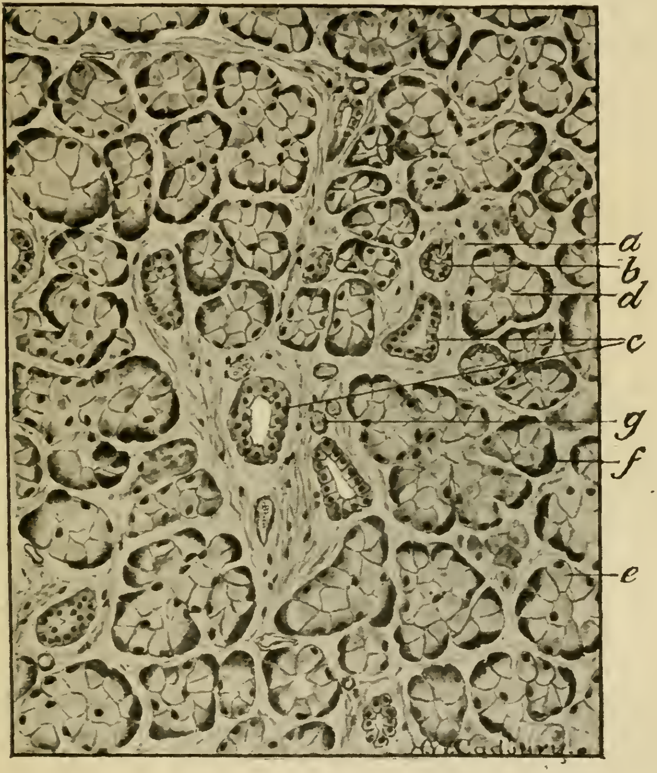


FIG. 183.—SECTION OF SUBMAXILLARY GLAND OF A FOX. *a*, Connective tissue; *b*, serous acinus; *c*, intralobular ducts; *d*, lumen of a mucous acinus; *e*, mucous cells; *f*, demilune of Heidenhain; *g*, capillary.

There are usually several ducts, called the **sublingual ducts** or **ducts of Rivinus.** If but one is present it is called the **duct of Bartholin.**

The *blood-vessels of the pancreas* pass into the interlobular connective tissue and accompany the ducts, to which they give branches. At the lobules small arterioles center and form a capillary plexus around the acini. Special arterioles pass to the islands and form a glomerular mass of capillaries that resembles those of the kidney. The extent will depend upon the size of the island and these vessels are characteristic of the pancreas. The blood is collected in *venous channels* and this venous blood no doubt contains the harmones elaborated by the islands; these are carried to the liver by the portal vein. By this vessel the harmones are delivered to the liver cells and here assist or cause the liver cells to store the excess sugar and to dole it out in only the required amounts.

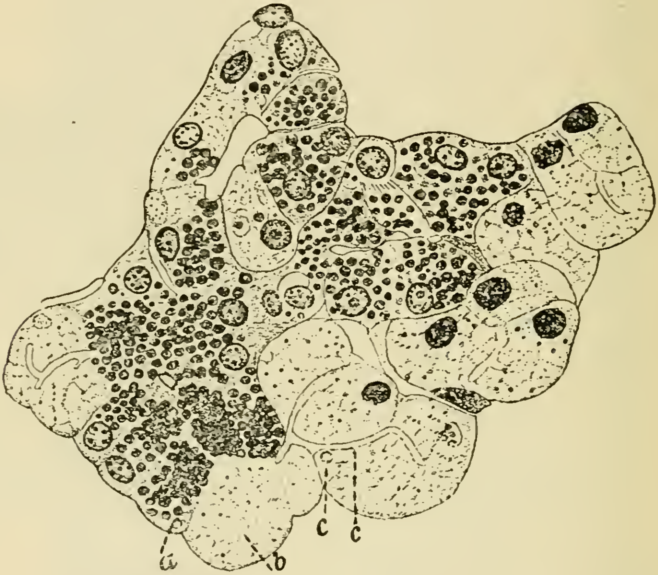


FIG. 184.—A PORTION OF THE SUBMAXILLARY GLAND OF A RABBIT.
a, A cell filled with secretory granules. *b*, later stage of secretory activity with the granules swollen; cells are clear and show a reticulum; *c*, *c*, secretory canaliculi. (*After E. Müller.*)

The *lymphatics* are numerous in the interlobular connective tissue where perivascular plexuses are formed. These drain the lymph spaces of the lobules.

The *nerves* are of the *sympathetic system* and accompany the vessels in the interlobular tissue where small ganglia may be numerous. Branches supply the muscle of the vessels and ducts and others pass into the lobules and form a meshwork around the acini and pass between the epithelial cells. In the pancreas of the cat Pacinian bodies are very numerous.

The *blood-vessels of the parotid, submaxillary* and *sublingual glands* are very numerous and pass into the glands in the same manner. Within the lobules a rich capillary plexus is formed around the acini and the endothelium of the capillaries may be in contact with the basement membrane in many places. The *venous blood* is returned in a corresponding manner.

The *lymphatics* are not so numerous as in the pancreas but are somewhat similar.

The *nerves* for the oral salivary glands are from both the *cerebral* and *sympathetic* nerve systems. These nerves pass into the interlobular connective tissue with the blood-vessels. In the lobules these fibers form plexuses around the walls of the acini, penetrate the basement membrane and terminate in fibrils or enlargements upon the epithelial cells. These *secretor fibers* are supposed to be derived from the cerebral nerves through the sympathetic. The fibers to the blood-vessels are *vasoconstrictor* and *vasodilator fibers;* the *former* are supposed to come from the cerebral nerves through the sympathetics and the *latter* directly from the sympathetics.

CHAPTER XI

RESPIRATORY SYSTEM

This **system** comprises the **nares, nasal fossæ, upper part of the pharynx,** the **larynx, trachea, bronchi, lungs** and **pleuræ.** Although there is no direct connection, the **thyreoid** and **parathyreoids** are included in this Chapter.

The **nares** are the two openings that lead into the nasal cavities. Here the skin of the nose changes to a mucous membrane and this area constitutes a *mucocutaneous junction.* Just within each of the nares is the **vestibule,** or first part of the nasal cavity; the lower part of this is the *respiratory part* and the upper the *olfactory portion;* the latter will be considered in another section.

The **vestibule** is lined by a mucous membrane that consists of epithelial cells, basement membrane and tunica propria. The *epithelial cells* are of the stratified squamous variety that show a change from the keratinized epithelium of the skin to the more delicate type as found in the internal parts of the body. They resemble somewhat those of the lip at the mucocutaneous junction but are not quite as well developed. Near the outlet there are some very large hairs, the *vibrissæ* that possess no arrector muscles. These cells rest upon a thin *basement membrane* and this is supported by the *tunica propria* which is attached to the cartilages beneath. In this areolar tissue are found the roots of the hairs and connected sebaceous glands, some sweat glands, diffuse lymphoid tissue and at times a few small mucous and serous glands.

The mucous membrane of the vestibule continues as the mucosa of the nasal cavity of each side, and at the dorsal limit of the cavities becomes continuous with the mucosa of the nasopharynx.

The **nasal mucosa** likewise consists of *three layers.* The *epithelium* is, however, of the stratified ciliated or pseudociliated variety containing goblet cells in great numbers. Beneath these are the *base-*

ment membranes (which responds to the elastica stains) and *tunica propria.* The latter varies in thickness in the different parts. Over the conchal bones it is thickest and in the accessory sinuses thinnest. It consists of fibro-elastic tissue containing the vessels and nerves and a considerable quantity of diffuse lymphoid tissue and even solitary nodules. Mucous and serous glands are also numerous. Some smooth muscle tissue is present and this chiefly surrounds the venous channels in circular or longitudinal bands. The *blood-vessels* are very numerous and in the thicker parts of the mucosa may constitute *erectile tissue.* The tunica propria is attached to the periosteum of the bony boundaries of the nasal cavities.

The **accessory cavities,** the *frontal*, *ethmoidal*, *sphenoidal* and *maxillary sinues*, are lined with an extension of the mucosa from the nasal cavities proper. The mucosa is very thin, seldom over 0.02 mm. and is firmly attached to the periosteum of the bony boundaries. Glands are not numerous in these cavities.

The **nasopharynx** has a mucosa that is partially attached to the bony wall and partly attached to the fibrous and muscle coats that extend throughout the pharynx. The *mucosa* consists of stratified ciliated cells that rest upon a basement membrane beneath which there is a tunica propria consisting of areolar tissue. Goblet cells are numerous in the epithelial layer. Some small glands and diffuse lymphoid tissue are found in the tunica propria, as well as solitary nodules; the latter are especially numerous in the dorsal wall. When these hypertrophy in the child they constitute *adenoids.* This lymphoid tissue constitutes the *pharyngeal tonsil.* The mucosa is firmly attached to the bony dorsal boundary but laterally and ventrally it is loosely attached to the muscles of the palate and tongue. At the sides of the nasopharynx the epithelial cells are continuous with those lining the auditory tube. The tunica propria of the pharyngeal extremity of this tube contains a considerable amount of lymphoid tissue that is referred to as the *tubal tonsil.*

LARYNX

The **larynx** is a hollow, cartilaginous organ connecting the pharynx with the trachea. It consists of **epiglottis, vocal cords** and **larynx proper.**

The **epiglottis** is a projecting flap that protects the **glottis** during deglutition. It is covered by *stratified squamous* cells upon both sides, and these are continuous at the edges, and rest upon *basement membrane* and *papillated tunica propria*. The *latter* is composed of fibro-elastic tissue, and contains diffuse lymphoid tissue, and, also, some glands, near its attachment. In the epithelial portion of the ventral surface, *taste-buds* are found. Beneath the tunica propria is the *submucosa*, which consists of loose white fibrous connective tissue. In it is found a plate of *elastic cartilage* that gives the stiffness, and also the elasticity, to this organ.

The **vocal cords** comprise the **true** and the **false.** The *former* are the functionating structures, while the *latter* (*plicæ ventriculares*) are merely heavy folds of mucous membrane that seem to resemble the former. Mucous glands are said to be present in the plicæ. The true cords alone are of importance.

The **true vocal cords, plicæ vocales,** are covered by *stratified squamous* cells that are supported by *basement membrane* and *tunica propria*. The central portion consists of a *band of elastic tissue* that extends from the angle of the thyreoid cartilage to the vocal process of the arytenoid cartilage. The epithelial layer is usually thin and exposes the yellow color of the elastic tissue. A small nodule of elastic cartilage (Luschka's) is found in the ventroinferior part of each fold. They contain no glands.

Between the two sets of cords there is a space, or recess, on each side, called the *ventricle of the larynx*. This is lined with stratified squamous cells and diffuse lymphoid tissue is found in the tunica propria. The *saccule* is an offshoot of the ventricle and has 60 to 70 small mucous glands within its tunica propria which form a secretion that is squeezed out upon the vocal cords to lubricate them.

The *remainder* of the larynx consists of **mucous, submucous** and **fibrous** coats.

The **mucous** coat, including that of the ventricles, is lined by *stratified ciliated* epithelial cells. The *tunica propria* contains a great deal of diffuse lymphoid tissue. That portion of the **submucosa** adjacent to the tunica propria possesses a number of small *mucous* glands. In its peripheral portion, the *cartilage masses* are found.

The form of the larynx is given by the cartilages, which are chiefly *hyalin.* Those of *Wrisberg* and *Santorini*, *middle of the thyreoid* and the *apices of the arytenoids* are *elastic cartilage.*

External to the cartilage is the fibrous coat, which is composed of white fibrous tissue, supports the other coats, and connects the larynx to the surrounding organs or tissues.

The *arteries* are derived from several sources. The larger vessels pass to the submucous coat from which the smaller vessels are sent to the muscle and mucous coats. In the mucosa the capillaries form quite a plexus beneath the epithelium and around the glands. The blood is collected by *venous channels* that ultimately join the various thyreoid veins.

The *lymphatics* are numerous. They start in the mucous coat and the upper set passes through the thyreohyoid membrane and the efferents conducts the lymph to the nodes near the bifurcation of the common carotid artery. The efferents of the lower set pass through the cricothyreoid membrane and conduct the lymph usually to the inferior laryngeal node.

The *nerves* are from the *vagal* and *sympathetic nerves.* The cricothyreoid and part of the arytenoid muscles and the mucosa are supplied by the superior laryngeal nerve, while the remaining muscles are supplied by the inferior laryngeal nerves. These terminate in regular motor end-plates. The sympathetic nerves are for the muscles and glands. *Sensor fibers* pass to the mucosa where they terminate between the epithelial cells in a network of fine fibrils. *Taste-buds* are found on the ventral surface of the epiglottis.

TRACHEA

The **trachea** connects the larynx with the lungs, its lower end bifurcating to form the **bronchi**. It has **three coats, mucous, submucous** and **fibrous.**

The **mucous coat** is a continuation of that of the larynx. It is composed chiefly of *stratified ciliated* and *goblet* cells that rest upon the *basement membrane* and *tunica propria.* The *basement membrane* is usually quite prominent, and the *tunica propria* contains considerable diffuse lymphoid tissue. It consists of fibro-elastic tissue, in which the fibers have chiefly a longitudinal direction. That portion of the mucosa opposite to the attachment to the esophagus is lined, at times, by *stratified squamous* cells, and is usually irregular.

The **submucosa** is made up of white fibrous tissue, and supports the large blood-vessels and a large number of mucous glands, the *tracheal glands.* These lie in that portion near the tunica propria and the largest are in the *dorsal* part of the trachea. In the peripheral part are found the *cartilage rings.*

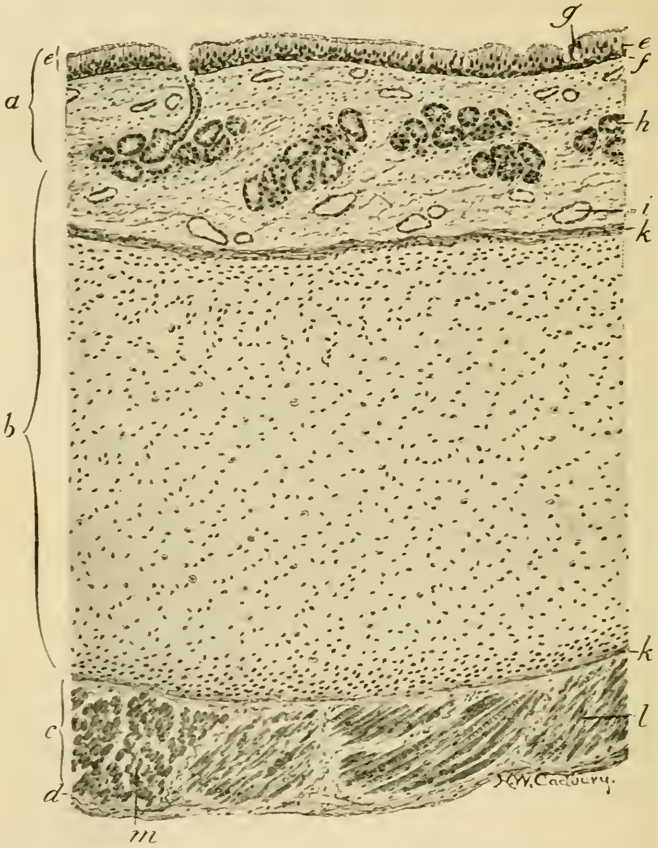


Fig. 185.—Cross-section of Segment of the Trachea.

a, Mucous coat; *b*, submucous coat; *c*, *d*, fibrous coat containing some voluntary striated muscle, *l*, *m*; *e*, stratified ciliated epithelium; *f*, basement membrane; *g*, goblet cells; *h*, mucous glands; *i*, blood-vessel; *k*, elastic tissue and perichondrium; *l*, longitudinal, and *m*, cross-sections of voluntary-muscle fibers.

These *so-called* rings are C-shaped masses of *hyalin cartilage*, with the open portion at the attachment of the organ to the esophagus.

These masses are thickest in front, and taper as the ends are reached. Although the cartilages are supposed to consist of one piece, they are commonly made up of a number of plates. The ends of the C's are connected by traversely and longitudinally arranged smooth muscle fibers, which are attached to the inner and outer perichondriums, and then bridge the spaces between the ends of the cartilage. This strip of muscle extends the length of the trachea, but no complete muscularis is present. The rings are sixteen to eighteen in number, and are separated from one another by white fibrous tissue.

The *inner transverse fibers* are the more numerous; the *outer fibers* are arranged in a few longitudinal bundles.

The **fibrous** coat lies outside of the cartilage rings, and consists of white fibrous and yellow elastic tissues.

The *blood-vessels* and *lymphatics* have their larger branches in the submucosa, from which smaller vessels extend to the other coats, and form capillaries.

The *nerves* are chiefly sympathetic.

The **bronchi** have the same general structure as the trachea. Usually the C-shaped ring of cartilage is replaced by a number of plates.

LUNGS

The **lungs** resemble *compound tubulo-alveolar glands*, the **bronchi** corresponding to the *excretory ducts*.

Each **lung** is invested by a *fibrous sheath*, covered almost entirely by serous membrane, the **visceral layer of the pleura**, which is reflected over the inside of the pleural cavity, as the *parietal layer of the pleura*. Between these two layers is the so-called *pleural cavity*, but as the lungs fill it in the living condition, it does not exist as a cavity. In it is found a small amount of lymph that lubricates the membranes.

The **pleuræ** have the same structure as *other serous membranes*. Each consists of *endothelial cells* and *subendothelial connective tissue* that pass from the lung over to the body wall. Stomata are not present and the subendothelial tissue is firmly attached to the subserous tissue that corresponds to the capsule of other organs. Over the thoracic wall the pleura is but loosely attached. The elastic fibers are numerous. The pleura extends into the fissures of the lung, covering the opposed surfaces and separating them completely.

The *blood-vessels* are numerous, forming extensive capillary plexuses. *Lymphatic plexuses* are also extensive.

The *nerves* are from the vagal and sympathetic nerves. The *latter* are *vasomotor* and the *former* are *sensor*. These sensor fibers may terminate in delicate fibrils, in small bulbous expansions or there may be lamellar corpuscles present.

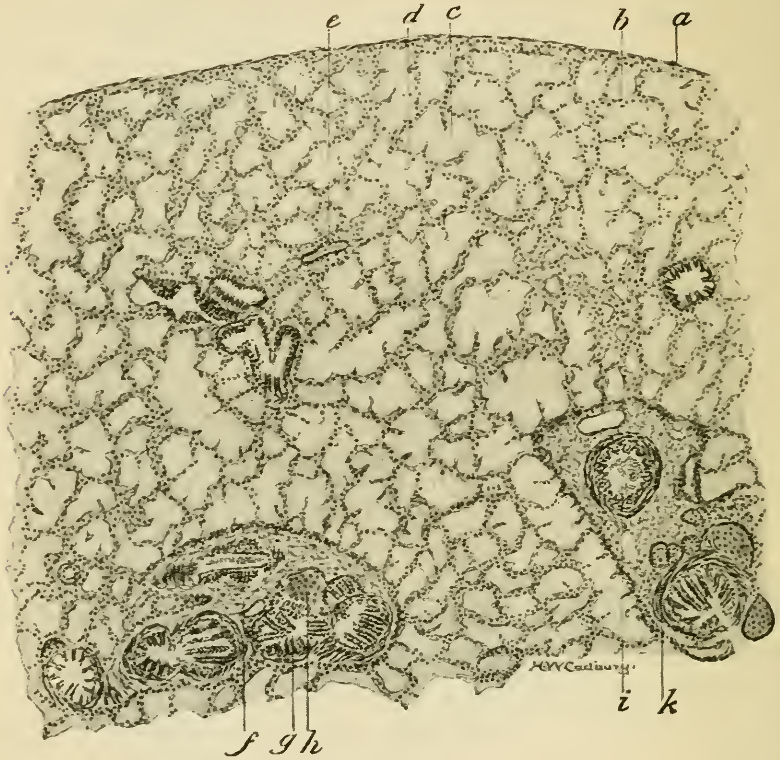


Fig. 186.—Section of Human Lung.

a, Pleura; *b*, alveolar septum; *c*, alveus, or air sac; *d*, alveolus; *e*, intralobular blood-vessel; *f*, interlobular blood-vessel; *g*, interlobular bronchial tube; *h*, cartilage; *i*, branch of pulmonary artery; *k*, gland.

The *subserous tissue* constitutes practically the *capsule of the lung* as it is continuous with the interlobular tissue of the organ. It consists of a thin layer of white fibrous and a considerable quantity of yellow elastic tissues. In guinea-pigs a network of smooth muscle tissue is found in this layer, while in the lion and leopard this layer is a strong elastic membrane.

Upon the medial surface of each lung there is an area of considerable extent where the vessels and ducts enter or leave the organ. This is limited by the reflection of the pleura and is the *hilus*, or *root*.

The **lungs,** like other glands, are merely systems of tubules that branch and rebranch, and are lined by different varieties of cells. Each is an *alveolo-tubular* gland, and although no liquid secretion or excretion is formed, it plays an important part in the excretion of gases and organic matter from the blood and in the oxygenation of the blood.

The **bronchi** divide like the ducts of any gland, and, ultimately, the small divisions called **bronchioles** are reached. Each **bronchiole** forms a system separate and closed from its neighbors. The **bronchiole** (0.5 mm. in diameter) divides into the **respiratory bronchioles** (0.3 to 0.4 mm. in diameter); these, in turn, give rise to **alveolar ducts** (0.2 mm.), which end as large spaces, the **alvei, alveolar sacs** or **air sacs** (0.3 by 5 mm.); along the walls of these divisions, are found small depressions the **alveoli,** or **saccules** (0.05 to 0.1 mm.), and these are the final divisions.

A **lobule** or **structural unit,** consists of the divisions of a bronchiole, and varies from 0.3 cm. to 3 cm. in diameter. It is surrounded by white fibrous tissue containing larger vessels and ducts, which are called interlobular, are over 0.5 mm. in diameter, and contain cartilage. The alvei, or air sacs, are separated from one another by yellow elastic tissue, in which a dense capillary plexus is found. In some animals the lobules are more distinctly outlined by the abundant interlobular connective tissue. The *ultimate lobule* is one alveolar sac, or infundibulum, with its six to eight alveoli. These are grouped together to form *secondary lobules* and several of these form a large division. All are bound together and separated from one another by connective tissue that supports the vessels and nerves. These lobules are roughly pyramidal in shape with the bases toward the surface of the lung and the apices toward the root.

As the **bronchus** divides and redivides, the tubules contain less and less cartilage. The first important change is the formation of a complete investment of cartilage, composed of a number of plates. As this occurs, the *muscle* tissue begins to increase, so that soon a distinct layer is seen internal to the cartilage. The lining cells are *stratified ciliated*, but the whole mucosa becomes irregular and corrugated, due to the formation of longitudinal folds; as the divisions become smaller, the cartilage diminishes. The *glands* disappear when a diameter of 1 mm. is reached. The cartilage is retained until a diameter of 0.5 mm. is attained.

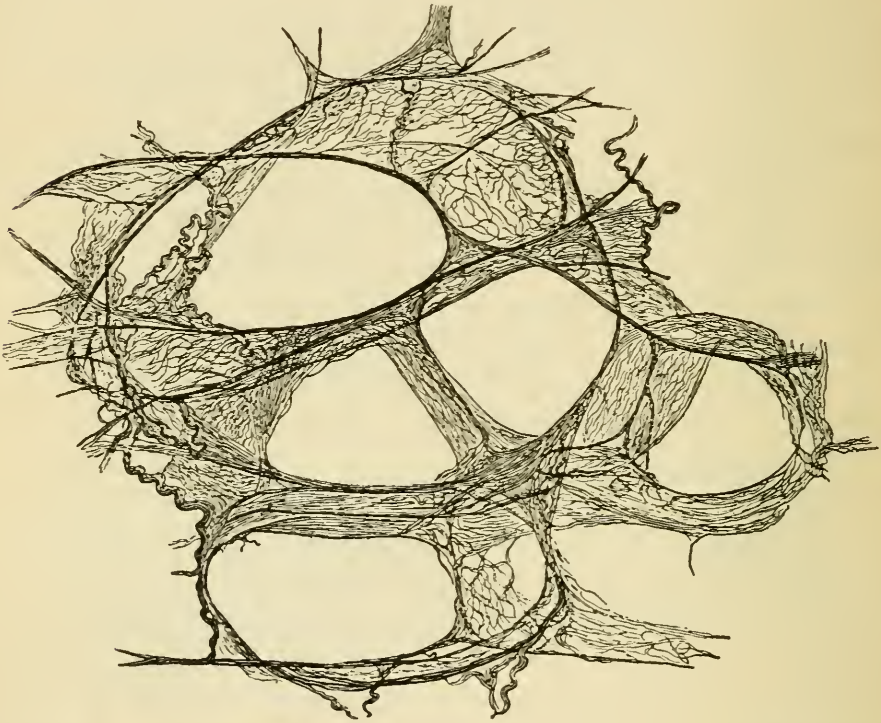


FIG. 187.—RETICULUM OF THE ALVEOLI OF THE LUNG. (*After Mall.*)

Such a tubule is a **bronchiole** and it constitutes the apex of a secondary lobule. It is lined by *simple ciliated epithelial* and *goblet* cells, supported by a *basement membrane* and an elastic *tunica propria*. External to this, the *circular muscle fibers* are quite prominent, and as a result, folds of the mucosa are formed. The external *fibrous* tissue contains elastic fibers, as well as vessels and nerves. This blends with the interlobular tissue.

The **respiratory bronchioles** arise by a division of the above tubules. They are short and are lined partially by *simple ciliated* and partially by *nonciliated* cells. The *former* are of the *simple* variety, and few in number. The *nonciliated* cells at first are *columnar*, but quickly give way to *low cuboidal* and *flattened* cells. The last named are called *respiratory epithelium.* Along the walls of the tubules, little depressions, the *alveoli*, are seen, and here the *respiratory epithelium* is marked. Muscle fibers are found beyond the tunica propria, and elastic tissue becomes more abundant.

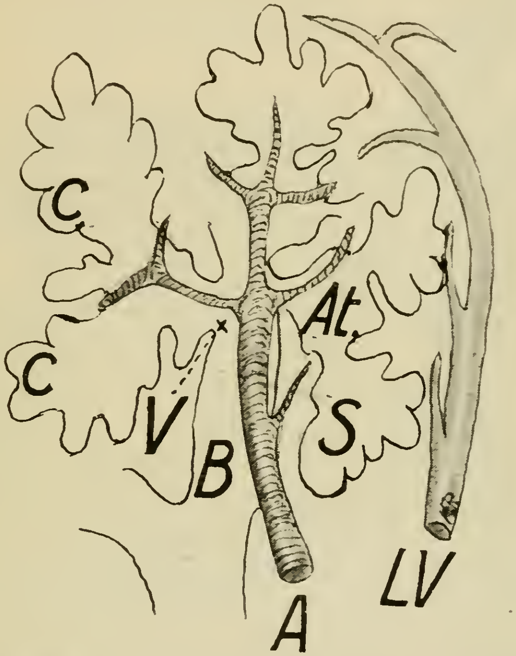


FIG. 188.—SCHEME OF THE TERMINATION OF A BRONCHIAL TUBE. *B*, Bronchiole; *V*, vestibule; *At*, atrium; *S*, air-sac; *C*, *C*, Alveoli; *A*, lobular arteriole; *LV*, lobular venule. (*After W. S. Miller.*)

The **alveolar ducts** or **infundibula** contain many alveoli lined by *respiratory epithelium*, which consists of thin, nonnucleated plates of various sizes, arranged individually or in groups. The smaller cells are derived from the cuboidal cells and are flattened by inspiration, and the larger are formed by a fusion of the smaller ones. The walls of these ducts consist of tunica propria, muscle tissue and considerable elastic tissue circularly arranged. The smooth muscle is in scattered bundles but at the end of the duct forms a ring.

The alveolar duct leads into the **alveus, air sac,** or **alveolar sac.** On the walls of this part are the small depressions, the **alveoli** or **saccules.** These are separated from one another by minute partitions, or *septa*, that consist of *elastic tissue* covered by *simple squamous* cells, the *respiratory epithelium.* The **alveoli** of a system are said to communicate with one another by means of small channels, or *pores*, but Miller states that these are not present in the cat. At the base of the alveolus, the elastic tissue is formed into a thick ring. In the meshwork of the elastica of an alveolus is found a dense plexus of blood-capillaries. The amount of elastica allows a great increase in size of the air sacs (2 or 3 times).

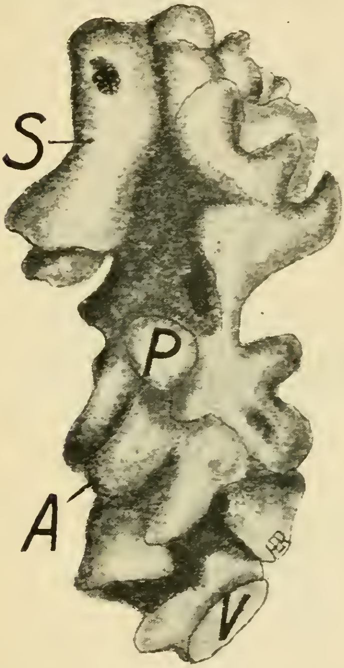


Fig. 189.—Cast of a Single Air-sac of a Dog's Lung.

A, Atrium; *V*, vestibule; *S*, air-sac; *P*, neck of air-sac cut away. The smaller projections are the alveoli. (*After W. S. Miller.*)

The alveoli vary in size in the different animals; in adult man, under moderate distension they measure about 0.25 mm. but vary up to 0.1 to 0.4 mm. In the cat and dog they are visible upon the surface of the lung. They are larger at the surface of the lung than deeper in. In the infant the measure usually under 0.12 mm. and increase from that on to old age. They are larger in the male than in the female. Each lung is said to contain from 300 million to 400 million alveoli in the adult condition.

From W. S. Miller's careful studies of the structure of the lungs, the terminal bronchioles terminate as follows: Each *respiratory bronchiole* divides into one or more *alveolar ducts*, which widen at their outer ends. Each duct opens into several *atria*, which, in turn, communicate with the *air sacs*, or *alvei*, on the walls of which are the *alveoli*.

The *circulatory system* is peculiar. As in the liver, *two* sets of vessels enter, the *pulmonary* and *bronchial*, but, unlike those of the liver, they do not unite to form a single system, but remain individual. There is some anastomosis between the two systems of vessels.

The *pulmonary artery* conveys the blood to be oxygenated and is the *nutrient vessel of the functionating epithelial cells.* It branches at the root, and the divisions follow those of the bronchus very closely, one for each division. Between the lobules, its branches are the *interlobular divisions,* and these penetrate the lobules and *one branch accompanies each* division of the terminal bronchiole. These form the *densest capillary plexus of the body,* within the elastica of the alveoli. Here the endothelial cells of the capillary, and the squamous epithelial cell of the alveolus, separate the blood from the air. Such an exceedingly thin membrane allows the interchange of oxygen and effete gases, and also the absorption of nutrient matter by the epithelial cells, and the outward passage of the waste matter. At the periphery of each lobule the blood is collected by the *venous* radicals of the *pulmonary vein,* and these unite to form the *interlobular branches,* that ultimately form the *pulmonary veins.* These

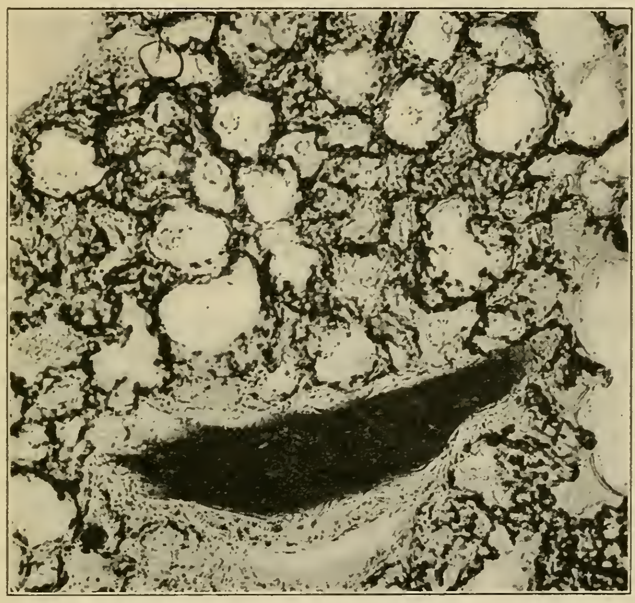


FIG. 190.—SECTION OF AN INJECTED LUNG OF A DOG.
(Photograph. Obj. 16 mm., oc. 7.5 X.)

interlobular veins run an independent course and are not so close to the smaller bronchial tubes as the arterial branches are.

The *bronchial artery* branches somewhat as the pulmonary artery, but its divisions *do not penetrate to the same degree.* The branches of the bronchial artery lie in the walls of the bronchial tubes and nourish them, *but not the respiratory epithelium.* Between these two sets of vessels, the pulmonary and bronchial arteries, there is some anastomosis, so that the pulmonary veins carry some of the bronchial artery blood from the lungs. The bulk of the bronchial blood, however, is collected by the divisions of the bronchial veins that finally empty into the *vena azygos*, *right* and *left* (or *left superior intercostal*).

From this it is readily seen that the bronchial arteries supply only the larger bronchial tubes. All of the smaller ones (those within the lobules), the alveolar ducts, alveoli, intralobular tissue and the pleura are supplied or nourished by the pulmonary artery.

The *lymphatics* accompany the veins and comprise a *superficial* and a *deep set.* The *former* lies under the pleura and its efferents pass the lymph into the deep set. These *deeper lymphatics* start in the lobules in the intercellular spaces; the vessels lie in the interlobular tissue and accompany the veins. The bronchial tubes of large size may have a plexus of lymph vessels in the mucous coat and another in the submucous coat peripheral to the cartilage. These communicate with those around the pulmonary artery and vein branches. In the interlobular connective tissue there may be considerable diffuse lymphoid tissue and solitary nodules; lymph nodes may be found at the bifurcation of the bronchial tubes. These usually contain numerous dark granules that represent inhaled dust particles. These are conveyed to the lymphoid structures by the leukocytes that have a phagocytic action.

The *nerves* are derived from the *pulmonary plexuses* that contain both sympathetic and vagal fibers. The *motor fibers* are for the muscle tissue of the bronchial tubes and the blood-vessels and the *sensor fibers* are for the mucosa of the bronchial tubes and the epithelium of the alveoli.

The following are the epithelial cells that line the various portions of the respiratory tract:

Nares	First part	Stratified squamous.
	Second part	Stratified ciliated.
Pharynx		Stratified ciliated.
Larynx	Epiglottis	Stratified squamous.
	Vocal cords	Stratified squamous.
	Remainder of Larynx	Stratified ciliated.
Trachea		Stratified ciliated.
Bronchi		Stratified ciliated.
Bronchial Tubes		Stratified ciliated.
Bronchioles		Simple ciliated. Simple columnar. Simple squamous (respiratory).
Alveolar Ducts		Simple squamous (respiratory)
Alveoli		Simple squamous (respiratory).

THYREOID BODY

The **thyreoid body** is a *ductless*, *compound tubular gland*, and consists of two large *lateral lobes* united by a narrow band, the *middle lobe*, or *isthmus*.

The organ is surrounded by a *capsule* of dense white fibrous tissue that sends in septa, which divide the gland into *lobes* and *lobules*. These divisions are irregular, and the lobules are composed of a number of short *tubules*, or vesicles, sometimes called *follicles*, that vary considerably in diameter. Each *tubule* is oval or round in shape and is lined by *cuboidal epithelial cells* that rest upon a *basement membrane;* outside of this is the *intralobular*, or *intertubular*, connective tissue that supports the blood-vessels. The cells are said to be of two kinds: (1) *Chief cells;* (2) *colloid cells.* The first are said to become the second and these in turn change into the colloid substance. The cytoplasm contains granules that are acidophilic in reaction. Fat droplets and granules that give the colloid reaction are also found. Intercellular capillaries are said to exist between the cells. In the tubules is seen a peculiar, homogeneous substance, the *colloid substance*, that is supposedly the result of the activity of the cells. If a fresh organ be cut a glairy substance oozes out. It has a yellowish color, and as blood-cells are frequently seen in it, the color may be due to the hemoglobin from these. It contains iodin in the form of *iodothyrin.* Sometimes, the *colloidal* *material* is shrunken, and then its edges are crenated; in such tubules, the epithelial cells are drawn away from the basement membrane. Gulland and Goodall found granules of iron in the interlobular tissue cells and in the epithelial cells of the tubules. These granules were most abundant in those tubules in which the colloid substance was small in amount. The colloid material and cells vary in appearance in different individuals; this difference may depend upon diet and nutritional conditions.

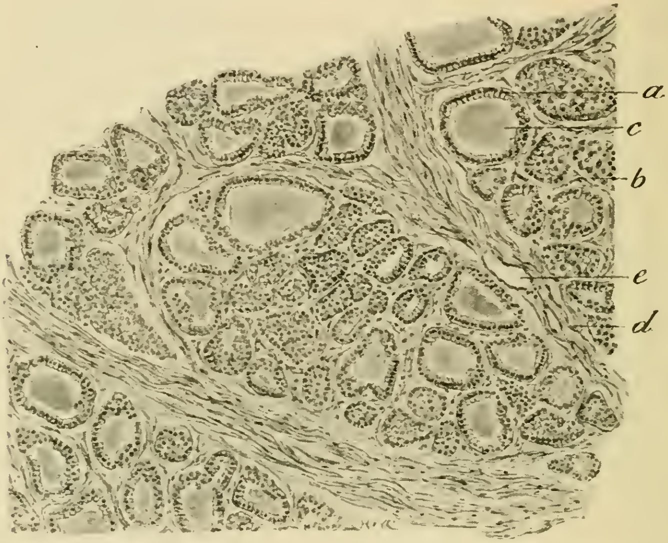


Fig. 191.—Section of Human Thyreoid Gland.
a, Epithelium; *b*, basement membrane; *c*, colloid substance; *d*, interlobular connective tissue; *e*, interlobular vein.

It is not unusually found that the colloid substance in the same tubule is of different reaction, most of its responding to plasmatic stains, while a smaller amount, centrally located and surrounded by the preceding, responds to the nuclear stain.

Blood-vessels are numerous, and dense plexuses are formed around the tubules. It is thought that the colloid material may represent an internal secretion that is absorbed by the blood-vessels, or perhaps the lymphatics.

The *lymphatics* are numerous, and lie between the tubules. *They often contain some of the colloid substance.*

The *nerves* are derived from the sympathetic system. They form fine plexuses in the walls of the tubules; from this terminal fibrils end upon and between the epithelial cells. Other branches pass to the muscle tissue of the vessels.

PARATHYREOIDS

The **parathyreoids** are usually *four* in number, two of which lie in close relation with each lateral lobe of the **thyreoid.** They are small, and the epithelial cells are usually of the *glandular type*, and are arranged in *groups*, or *chains*, *forming a network*, or *even tubules*.

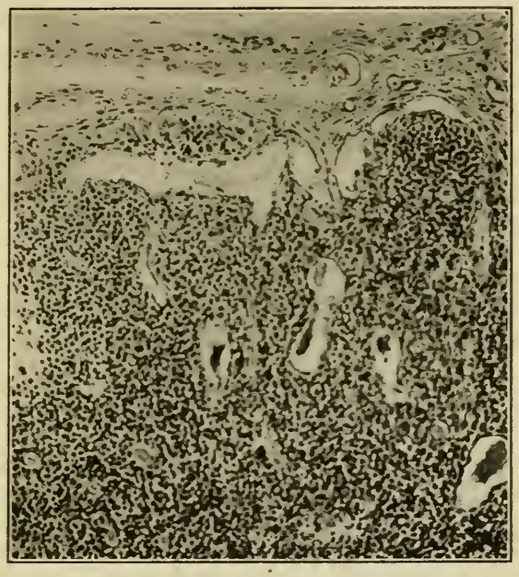


FIG. 192.—SECTION OF HUMAN PARATHYREOID GLAND.
Some of the spaces show colloid substance. (Photograph. Obj. 32 mm., oc. 5 X.)

Each is surrounded by a capsule of white fibrous tissue that is thin but tough. Within this there is a delicate reticulum that supports the epithelium, vessels and nerves. These cells respond very readily to the protoplasmic stains and are usually quite deeply stained, in marked contrast to the cells of the thyreoid body. Rulison states that there are two kinds of cells: The *principal cells* are the smaller and most numerous. These are oval in shape, the cytoplasm is clear and the nucleus vesicular in appearance. The *acidophilic cells* are larger cells in which the cytoplasm contains a number of acidophilic granules. The nucleus is smaller and contains much chromatin. Between the cells is white fibrous connective tissue that supports quite a capillary plexus. Occasionally, *colloid material* is seen in the tubules. When the thyreoids are removed and the parathyreoids remain, they hypertrophy and carry on the function of the removed organs. According to some investigators, the parathyreoids do not assume the function of the thyreoids. Removal of the parathyreoids is fatal within a short time.

CHAPTER XII

THE URINARY SYSTEM

The **urinary organs** comprise the **kidneys, ureters, bladder** and **urethra.** On account of its proximity to the kidney, the **adrenal** will also be considered.

The **kidney** is a *compound tubular* gland, and, next to the liver, the largest in the body. The kidneys represent the urea excreting organs while the ureters, bladder and urethra are the conducting tubes, reservoir and outlet tube by means of which the urine is carried, stored and emptied. The kidneys lie in the dorsal portion of the abdominal cavity dorsal to the peritoneum. Each is surrounded by a considerable quantity of adipose tissue called the *perirenal* fat. The quantity depends upon the nutritive condition of the body and in some animals constitutes an enormous mass in which the kidney appears as a very small part. Some of this fat persists even though the animal dies of starvation.

The kidney is surrounded by a thin **capsule** of white fibrous tissue that normally strips readily from the organ. This is of great importance, when the organ is studied pathologically. It consists of white fibrous tissue containing some smooth muscle and elastic fibers. It continues into the organ in the form of small trabeculæ which form the gross framework of the organ; within this there is a delicate network of *reticulum* that supports the parenchyma, vessels and nerves. At the hilus the capsular tissue blends with that of the pelvis of the ureter and forms a mass of areolar tissue that surrounds the pelvis and blood-vessels and fills the renal sinus. Adipose tissue is deposited in this tissue. Although the trabeculæ tend to divide the kidney into lobes and lobules only parts of the lobes are distinct in the adult condition. These are represented by the apices of the medullary pyramids, the bases of which are somewhat separated from one another by the columns of Bertin. The cortical portion shows no lobulation, but in the fetal condition the surface of the kidney is nodulated and these nodules indicate the lobules; by birth these lobules are all fused and give the surface a smooth, even contour in most animals. In reptiles, birds and some mammals

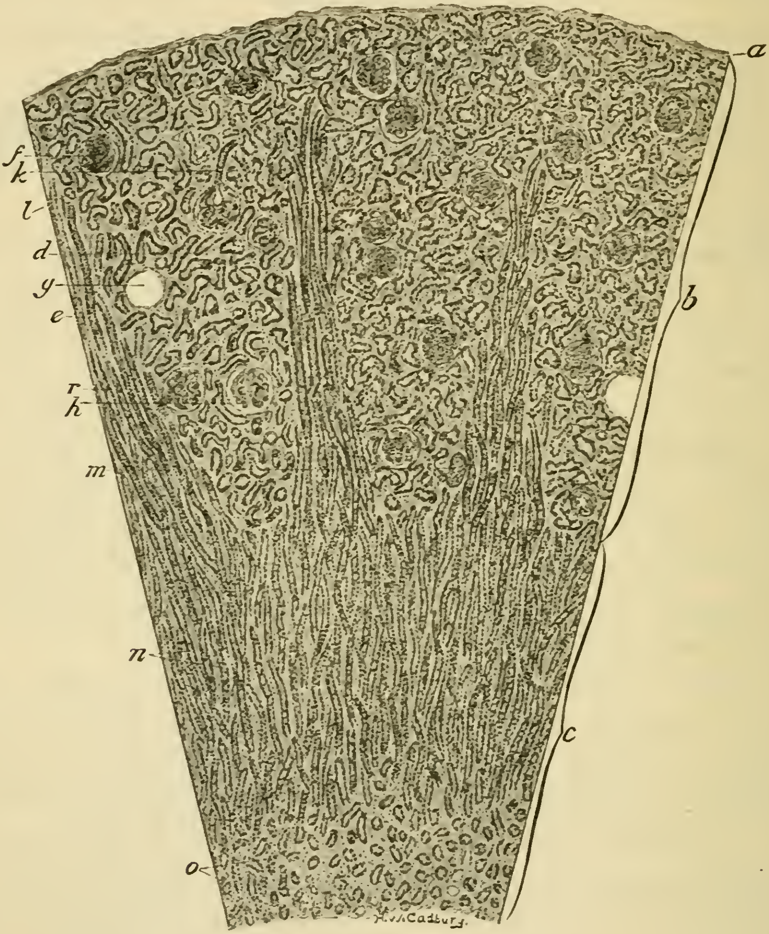


Fig. 193.—Section of Human Kidney showing Cortex and Medulla.

a, Capsule; *b*, cortex; *c*, medulla; *d*, labyrinth; *e*, medullary ray; *f*, renal bodies; *g*, area in which renal body has dropped out; *h*, capsule of Bowman; *i*, glomerulus; *k*, afferent arteriole; *l*, neck of uriniferous tubule; *m*, tubules of labyrinth; *n*, longitudinal sections of collecting tubules; *o*, cross-sections of collecting tubules.

these lobulations are retained throughout life. In the guinea-pig, cat and rabbit no lobulation whatever is noticeable. A *renculus* is represented by a single medullary ray surrounded by the adjacent convoluted tubules of the labyrinth. The interlobular vessels constitute its boundary.

Beneath the capsule is the kidney substance that comprises the *interstitial tissue*, or supportive substance already mentioned, and the *parenchyma*, the functionating part that consists of epithelium arranged in the form of tubules. These uriniferous tubules are comparatively long and have a very irregular course. These consist of a single layer of epithelial cells, basement membrane and tunica propria. The homogeneous substance of the basement membrane is very resistant to acids. When pieces of the kidney are subjected to hydrochloric acid the interstitial tissue is dissolved but the basement membrane remains intact and holds the tubule together in its entirety. In this way beautiful mounts of these tubules may be obtained. In special preparations Mall has shown that the basement membrane contains delicate fibrils that are continuous with the reticulum of the interstitial tissue. These fibers are circularly and longitudinally arranged. These are imbedded in the homogeneous substance which alone shows in the ordinary preparations. The tunica propria of the convoluted tubules is not prominent. Along the medial margin of the organ is a deep notch, the *hilus*, at which the renal artery and nerves enter and the renal vein, ureter and lymphatics leave.

When the organ is sectioned, upon microscopic examination it is seen to consist of an outer margin, the **cortex,** and an inner broader portion, the **medulla.** Just within the hilus is seen a space, the **sinus.** In the ordinary condition this is not a space as it contains the pelvis of the ureter, the branches of the renal artery, the tributaries of the renal vein, nerves and lymphatic trunks imbedded in adipose tissue. If these structures be removed then the space is demonstrable.

The **cortex** constitutes the outer third of the organ, and is further subdivided into **medullary rays** and **labyrinth.** This division is represented by the alternating dark and light bands, which are at right angles to the capsule, and gives a striated appearance to the cortex.

The **medullary rays,** or **pyramids of Ferrein,** consist, microscopically, of the straight portions of the tubules that extend from the medulla into the cortex, surrounded by the intertubular, or interstitial reticulum. They never extend to the capsule, but diminish in width as the outer portion of the cortex is approached.

The **labyrinth** lies between the medullary rays, and is composed of the **Malpighian,** or **renal, corpuscles,** the *starting points of the tubules*, and the *convoluted portions of the uriniferous tubules*. These are supported by the *interstitial connective tissue* that contains the blood-vessels.

The **renal corpuscles** are found *only in the cortex*, and here are *limited to the labyrinth*. There are probably over a million of these renal corpuscles in each human kidney. In the cat there are 16,000 in each kidney. Each one consists of a tuft of *arterial capillaries*, the **glomerulus,** or **renal tuft,** surrounded immediately by a delicate double membrane of *simple squamous* cells, resting upon a *basement membrane*. The *inner* layer lies upon the tuft, and the *outer* forms the wall of the tubule. This membrane is **Bowman's capsule,** and, with the tuft, comprises the **renal corpuscle.** The tuft itself is not a simple structure. The arteriole, upon entering, divides

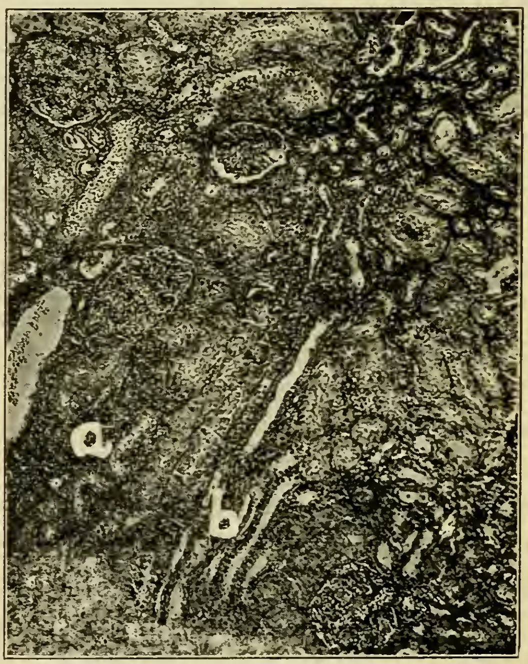


FIG. 194.—SECTION OF THE CORTEX OF THE HUMAN KIDNEY. *a*, Labyrinth; *b*, medullary ray. (Photograph. Obj. 16 mm., oc. 7.5 ×.)

into a number of branches, each of which forms a set of capillaries. This apparent lobulation is quite distinct. As these capillaries unite to form an efferent arteriole, this arrangement is called a *retia mirabilia*. The afferent arteriole is larger than the efferent.

The **medulla** is sharply outlined from the cortex, microscopically, by the *absence of renal corpuscles* and the regularity of the tubules. At the junction are to be found the great vessels, and this portion is called the *boundary zone*. The **medulla** consists of the **medullary, or Malpighian pyramids,** separated from one another by the **columns of Bertin.**

The **medullary pyramids** are ten to sixteen in number. Their bases continue with the cortex, and their apices are directed toward the hilus and project into the sinus. Each consists of a large number of straight tubules that become fewer in number as the apex is reached, where but fifteen to twenty are present. These are the **papillary ducts,** or **ducts of Bellini.** The tubules are supported by reticulum, in which the capillaries are found.

The **pyramids** are separated from one another by a narrow band of tissue that is, near the apices, chiefly white fibrous; toward the bases, the cortical parenchyma begins to enter into its formation. This is the *column of Bertin*, and within it are the large vessels that pass from the sinus to the boundary zone.

The pyramids represent the embryonal condition when the whole organ consisted of lobes. At birth, usually, the bases of the lobes have fused to form the cortex, but the inner ends never reach that condition. The *columns of Bertin* then represent the interlobar connective tissue and spaces. In some animals the lobulation never disappears.

The uriniferous tubule has a very peculiar and convoluted course. It starts in the cortex, and passes into the medulla, to return to the cortex for its final passage through the medulla. It originates at the *renal corpuscle*, which is merely the invaginated end of the tubule, containing a tuft of capillaries. From this, the presence of a double capsule can be readily understood.

The *inner layer* of this capsule covers the tuft of capillaries following all of its irregularities; the only gap is where the arterioles make connection with the glomerular tuft. The *outer layer* is continuous with the inner at the point of this reflection over the arterioles. The external surface of the glomerular layer and the internal surface of the outer layer are lined with a *single layer of squamous epithelial cells* that are almost in contact with each other, the narrow space represents the lumen of the first part of the uriniferous tubule. The outlet of this space is opposite to the point of connection of the blood-vessels and represents the neck of the uriniferous tubule. The epithelial cells contain an oval nucleus and the cytoplasm is clear. The layer of cytoplasm, however, is so thin that the nucleus bulges. These cells rest upon a thin *delicate basement membrane* that is homogeneous and is supported by a thin layer of white fibrous tissue that represents the *tunica propria* of the ordinary mucous membrane. This layer is said to be thicker in those corpuscles near the medullary region of the cortex. The epithelial cells of the internal layer of the capsule are in direct contact with the endothelium of the capillaries simulating a sinusoidal condition. This facilitates the rapid discharge of water into the capsule during the formation of the urine.

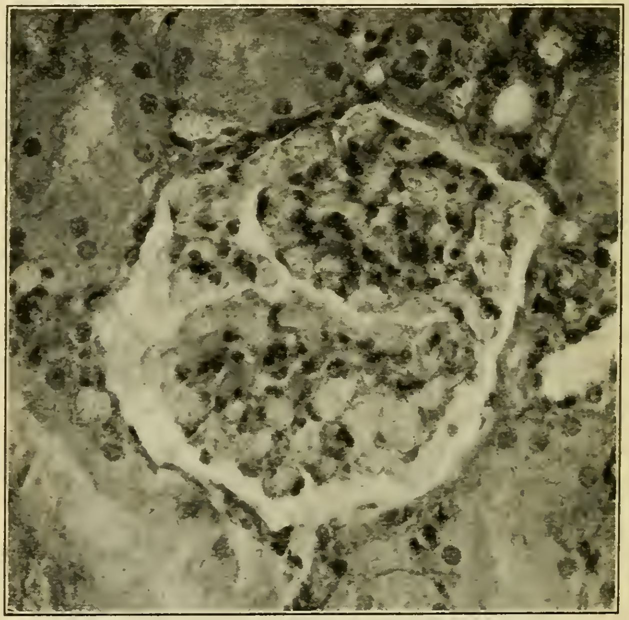


FIG. 195.—SECTION OF A RENAL CORPUSCLE OF THE PRECEDING SECTION UNDER HIGHER MAGNIFICATION. (Photograph. Obj. 4 mm, oc. 5 X.)

The *neck* is one of the narrowest and most constricted portions of the tubule. It is short and rapidly goes over into the first convoluted portion. It is lined by *simple squamous*, or *low cuboidal epithelial cells*. These rest upon the basement membrane and tunica propria.

The *proximal convoluted tubule* is the next division and is called the distal convoluted tubule in embryology. This part is very irregular and tortuous in its course. It lies in the labyrinth and is the longest and widest portion of the actively functionating portions of the tubule. The two convoluted tubules form the greatest part of the cortex. The *cells* are of the *columnar type* but they are irregular in height so that not only is the tubule tortuous but the lumen itself is irregular and tortuous. While the basal and lumen boundaries of the cells are distinct the lateral boundaries are not readily seen. They may be outlines with silver nitrate solutions. Under this condition the outlines are seen to be very irregular, resembling the sutures of the skull as the cells articulate with one another. The cytoplasm varies in appearance. In the lumen end of the cell it is usually clear or faintly striated and presents a cuticular border. This does not always show as this portion of the cell is easily injured. The basal portion of the cell contains the lightly staining nucleus in which the chromatin is rather evenly scattered. The cytoplasm shows striations or cytoreticulum. The granules are arranged in the form of filaments (probably mitochondria) connected with the

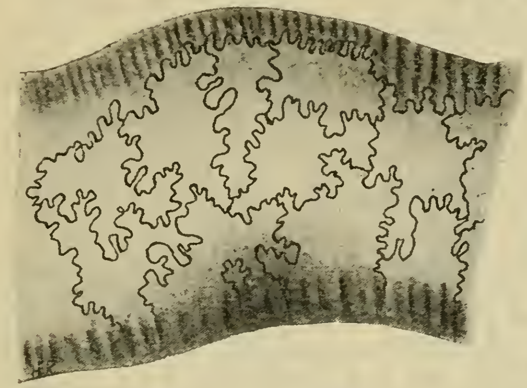


Fig. 196.—Portion of a Longitudinal Section of a Convoluted Tubule Prepared by the Golgi method. The irregular lines represent the outline of the cells. (*After Landauer.*)

formation of urinary excretions. Under the influence of diuretics the granules in the cells of the convoluted tubules become fewer, larger and scattered. Diet also affects them and they are more numerous after a pure meat diet. These granules are probably derived from the disintegrating filaments that probably represent mitochondria. The state of secretory activity of the cells is indicated by a dome-like swelling of the lumen area of the cells; here a centrosome may be observed and in some animals the convoluted tubule cells may be ciliated. These probably indicate the ciliated cells of the nephridia of invertebrates. In hibernating animals these cells are tall and nearly occlude the lumen, representing the resting or inactive stage.

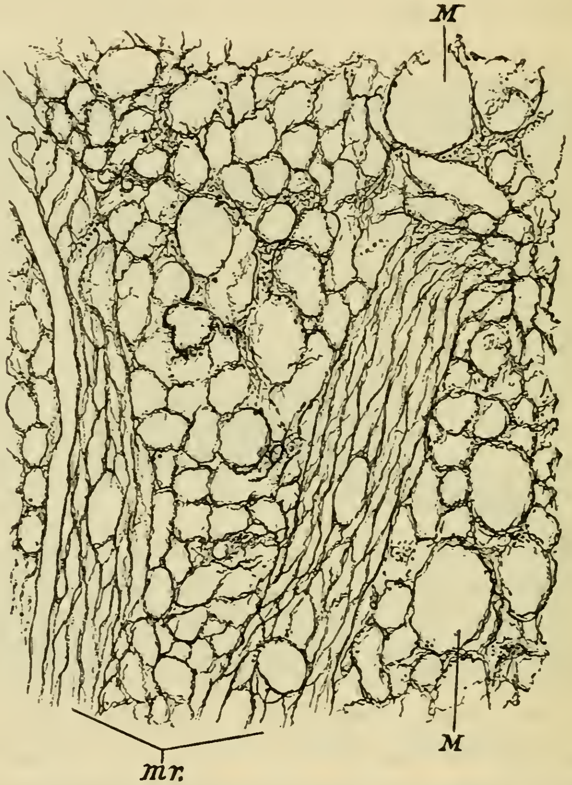


Fig. 197.—Interstitial Tissue of the Cat's Kidney.

M, M, Spaces occupied by renal corpuscles; *mr,* spaces occupied by the tubules of the medullary rays; the other parts represent the labyrinth. (*After Disse.*)

The *descending limb of Henle's loop* is the continuation of the preceding part. It is one of the narrowest parts of the uriniferous tubule and extends from the cortex into the medulla. It is lined by *simple squamous epithelial cells* in which the cytoplasmic layer is thin and the nuclei bulge. The cytoplasm is finely granular and the nucleus stains quite deeply and bulges. As the nuclei sort of alternate their projection into the lumen makes the cavity of this part of the tubule irregular. The cells rest upon the basement membrane and beyond this is the tunica propria.

The *loop of Henle* and the *ascending limb* are the continuations of the descending limb. The position of the loop depends upon the position of the renal corpuscles; if these are near the capsule of the kidney the loops are near the cortico-medullary boundary zone; if the corpuscles are near the medulla the loops are deeper in the medulla. The loop may be of the same size and structure as the descending limb or may correspond in these conditions with the ascending limb. The ascending limb extends from the medulla into the cortex, is double the diameter of the descending portion and is lined therefore with cuboidal cells that are quite regular in height and have distinct outlines. The cytoplasm is usually finely granular and basal striations may be present. The nucleus stains well.

The *distal convoluted tubule* is called the proximal convoluted tubule in embryology. This is smaller in diameter and shorter than the first convoluted tubule but like it lies in the labyrinthine portion of the cortex. The lumen is irregular here also because the epithelial cells are of unequal height. Outside of being shorter these cells resemble those of the proximal part in structure and function.

The *arched connecting tubules* and the remainder of the uriniferous tubules represent merely conducting portions. This tubule is short, lies in the cortex and is the connecting link between the last convoluted and the first collecting tubules. The cells are of the regular *cuboidal type* with distinct outlines and darkly staining nuclei. The cytoplasm is usually clear and stains lightly. The lumen is regular.

The *straight collecting tubules* have a straight course and begin in the cortex, pass into the medulla, where many join together increasing in size and terminate in the papillary ducts. In the cortex they form the medullary rays and in the medulla they are parallel to one another. The epithelial cells vary in form in the different portions. In the cortex where the diameter is least the cells are of the *cuboidal type;* as the diameter increases the cells become gradually *columnar* of a low and then of the tall type. The cytoplasm is clear, the nucleus stains well and the cell outline is distinct.

The *papillary ducts*, or *ducts of Bellini* represent the terminals of the uriniferous tubules. There are fifteen to eighteen of these ducts in each medullary pyramid apex and these represent the junctions of thousands of the straight collecting tubules. They are very great in diameter and the epithelial cells lining them are of the very *tall columnar type.* The cytoplasm is clear and the nucleus stains deeply. In some animals these ducts are lined with stratified columnar cells.

The various portions of the **uriniferous tubule** are distributed as follows:

Cortex.—In the **labyrinth** are found the *renal corpuscles, neck, first* and *second convoluted tubules.* In the **medullary rays,** the *upper ends of the descending* and *ascending limbs of Henle's loop* and *straight collecting tubules,* and the *arched connecting tubule.*

Medulla.—The *lower ends of the descending* and *ascending limbs* and *the loop of Henle* and the *straight collecting tubules* and *papillary ducts.*

The diameter of the different parts of the tubule varies. The **renal corpuscle** is large, measuring 120 *to* 200 *microns.* The **neck** averages about 15 *microns,* and the **proximal convoluted tubule** is quite irregular, but the average is about 50 *to* 60 *microns.* The **descending limb** is quite *narrow,* 10 *to* 13 *microns,* and the **ascending limb** *about* 25 microns. In the **second convoluted tubule,** the diameter again increases, averaging 40 to 45 *microns.* From the beginning of the **straight tubule** to the end, the diameter progressively increases 18 to 50 *microns;* so that the **papillary ducts** may have a diameter of 200 to 300 *microns.*

The *blood-vessels* have a characteristic distribution. The **renal artery** passes through the **hilus** and enters the **sinus,** where it divides into four or five branches, of which the greater number supply the ventral three-fourths of the kidney. The branches that go to the ventral pyramids carry three-fourths of this blood. The rest of the kidney is supplied by the dorsal branches. The branch that supplies each pole, derived from the ventral division, divides into *ventral*, *middle* and *dorsal branches*, which are in no way united. The trunks pass up through the *columns of Bertin*, where small branches are given off to the vessels and tissues, as the **interlobar branches.** These branches pass to the *boundary zone*, where they arch between the cortex and medulla, forming the **arterial arches, or arcade.** From the cortical side of the arch, the **cortical,** or **interlobular,** arteries are sent toward the capsule; from these, small arterioles **afferent,** pass to the *renal corpuscles*, enter and form several smaller branches, each of which breaks into a capillary tuft. From this, it will be seen that the renal tuft consists of several bunches of capillaries. Each capillary group is separate, and the vessels unite to form arterioles that leave the tuft as a single vessel, the **efferent** arteriole. *The blood is still arterial.* The **efferent** arterioles soon form dense plexuses of capillaries around the tubules of the labyrinth and medullary rays. Those capillaries near the boundary zone pass into the medulla and surround the tubules there. The *capillaries* become **venous** in character, and unite with others to form the **interlobular veins.** The **cortical artery** continues to the capsule, where it forms a star-shaped mass of venules, the **venæ stellatæ.** These are, in reality, the starting-points of the **interlobular veins,** which run parallel to the arteries of the same name, and empty into a **venous**

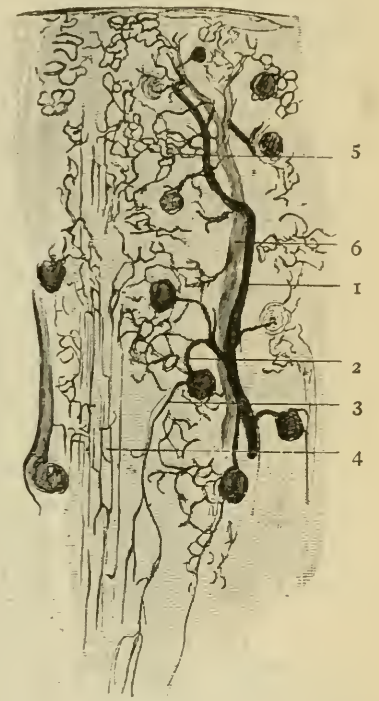


FIG. 198.—SECTION OF INJECTED KIDNEY OF GUINEA-PIG.

1, Interlobular (cortical) artery; 2, afferent vessel; 3, efferent vessel; 4, capillary network in medullary ray; 5, capillary network in labyrinth; 6, interlobular (cortical) vein. (*Stöhr's Histology.*)

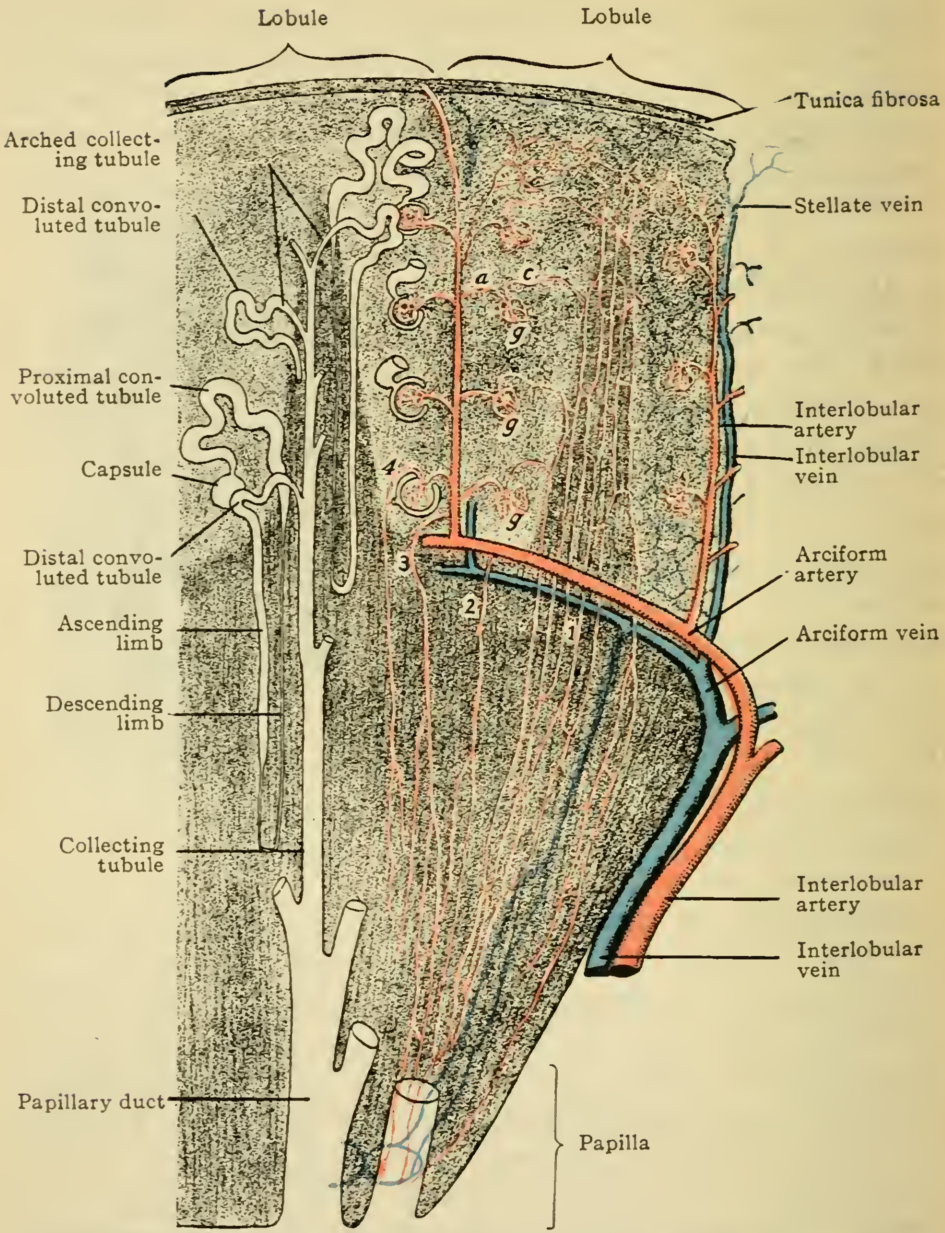

Lobule
Lobule
Tunica fibrosa
Arched collecting tubule
Distal convoluted tubule
Stellate vein
a
c
g
Proximal convoluted tubule
g
Interlobular artery
Interlobular vein
Capsule
4
g
Distal convoluted tubule
3
Arciform artery
2
1
Ascending limb
Arciform vein
Descending limb
Collecting tubule
Interlobular artery
Interlobular vein
Papillary duct
Papilla

Fig. 199.—Diagram of the Course of the Renal Blood Vessels. (*Lewis and Stöhr.*)

arcade that is formed at the boundary zone by the union of the large vessels. Such is the blood supply of the **cortex.**

The **medulla** receives its blood from the concave surface of the arterial arch. The arterioles given off have a straight course, and are the **arteriolæ rectæ.** They very soon break up into **capillaries** that surround the tubules of the medulla. Huber and others state that some of the arteriolæ rectæ are derived from the efferent glomerular arterioles nearest the medulla. These are the *arteriœ rectœ spuriœ* and possess no circular muscle fibers. They proceed in the same manner as the true arteriæ rectæ. These continue as **venous** radicals that unite to form straight veins, **venæ rectæ,** which empty into the **venous arch** on its concave surface.

The **venous arches** unite at the columns of Bertin, and pass down these, parallel to the arteries, as the **interlobar veins.** In the sinus, they unite to form the **renal vein.**

In addition to the branches from the renal artery the capsule also receives many branches from neighboring arteries and these anastomose with the end branches of the interlobular arteries. The vessels of the kidney, therefore, communicate with those of the perirenal fat, through the vessels of the capsule. This is of importance surgically. Direct anastomoses between arterial and venous vessels occur in this organ.

The *lymphatics* of the kidney comprise a *capsular set*, *cortical* and *medullary plexuses.* The capsular vessels receive lymph from the capsule and perirenal fat and the efferents convey the lymph partly to the deep set and partly to the lymph nodes of the lumbar region. The cortical vessels form a plexus in the interstitial tissue, receive some of the lymph from the capsular region and pass the lymph to the medullary plexus. The latter receives the lymph from the cortex and from the plexus of vessels in the interstitial tissue of the medulla and the efferents convey the lymph to the hilus and from there to the neighboring lymph nodes. These lymph channels accompany the vessels and are irregular in caliber.

The *nerves* are derived from both systems. They follow the vessels and in the sinus form a plexus around the pelvis of the ureter, containing ganglia. The nerves follow the vessels and envelop them in networks to the smallest divisions. Some of these nerves supply the muscles of the vessels and others pass to the tubules where their terminal fibers pass through the basement membrane and end between the cells in small knob-like terminals.

The kidney is the organ that *excretes the urine.* The liver is the organ that makes the urea which is then carried to the kidney to be excreted. The urine contains urea, uric acid, urates and inorganic salts such as chlorids, sulphates, and phosphates of sodium, potassium and calcium all dissolved or suspended in the water. The color, reaction and specific gravity will depend upon the amount of the solids and the proportion of water. As the blood courses through the capillaries of the cortical portion of the kidneys the columnar cells of the convoluted tubules remove the salts by a "selective power" and transfer them to the lumen of the tubule. Through the capsule of Bowman and the walls of the descending limb of Henle's loop in cortex and medulla, the water diffuses or osmoses and passing down the tubules dissolves and carries along the solids. If the water is in sufficient quantity these are all dissolved. If the water is not sufficient the more insoluble salts, like uric acid, will be only partly dissolved and the remainder will be present in the form of a sediment. Sometimes these salts form urinary concretions in the kidney or the bladder. Such concretions are readily seen in the cells of the convoluted tubules of reptiles, birds and some mammals. In addition epithelial cells are present in the urine and even casts of the tubules are found. The cells of the different parts of the tubule are readily recognized.

THE EFFERENT APPARATUS

The **efferent apparatus** consists of the **pelvis, ureter, bladder** and **urethra.**

The **pelvis** *is the upper, expanded portion of the ureter,* and lies in the sinus. It is very irregular, and is divided into two or three main portions, the **infundibula,** or **calices major,** which are arranged in little cup-like structures around the apices of medullary pyramids. The latter are the **calices minor,** and they are not equal in number to the pyramids as one calix surrounds the apices of two or three pyramids. The three coats, **mucous, muscular** and **fibrous,** extend throughout the ureter and bladder.

The **mucous membrane** consists of *transitional cells, basement membrane* and *tunica propria.* In the calyces minores the epithelium is of the simple columnar variety and is continuous with the same kind that covers the apices of the Malpighian pyramids and lines the papillary ducts. The epithelial cells of the remainder of the pelvis are of the transitional variety. The superficial cells are somewhat flattened and almost squamous. Just beneath these the cells are somewhat larger and pear-shaped while the deepest (basal cells) are polyhedral. These deeper cells divide by karyokinesis and these daughter cells replace the superficial cells as they desquamate. The superficial cells divide by the direct method.

The *tunica propria* consists of fibro-elastic areolar tissue in which there may be some diffuse lymphoid tissue. On the epithelial side it is papillated and very vascular. The capillaries may extend even into the deeper parts of the epithelial layer. Racemose glands are said to occur in the mucosa but Shäfer denies their presence.

The **muscular coat** consists of smooth muscle tissue that is not arranged in distinct layers. Bundles of muscle fibers extend into the fibrous coat.

The **fibrous coat** is a thin supportive layer of white fibrous connective tissue. Its fibers connect with those of the areolar tissue of the sinus and at the lines of reflection of the calyces minores upon the apices of the Malpighian pyramids this fibrous tissue blends with the interstitial tissue of the kidney.

At the caudal extremity of the sinus the pelvis becomes drawn into a small tube that is the *ureter.*

URETER

The **ureter** is the small tube connecting the kidney and the bladder, which organ it enters at an acute angle. Its coats are quite distinct and are *mucous, muscular* and *fibrous.*

The **mucosa** resembles that of the pelvis with which it is continuous. The epithelial cells are of the *transitional variety* and are arranged in four layers; the two basal layers are rounded or ovoid in form, the third layer somewhat pear-shaped and the superficial cells are large and cuboid in form, in the resting condition of the duct. *Intercellular bridges*, or *processes* connect the various cells together. The superficial cells may show two nuclei, a cuticular border is usually present and the cells usually divide by the direct method. When the tube is distended with urine then the cells become flattened temporarily. The tunica propria often sends delicate fibers into the deeper layers of the epithelium and capillaries may even be present here. The *basement membrane* is thin and is pierced by the fibers mentioned above. The *tunica propria* consists of areolar tissue that is looser near the muscle coat. In it are found some diffuse lymphoid tissue and even solitary nodules; in lower animals small racemose glands of the mucous type are also present. This mucosa is thrown into longitudinal folds in the empty condition of the tube and the lumen then is small and stellate in shape.

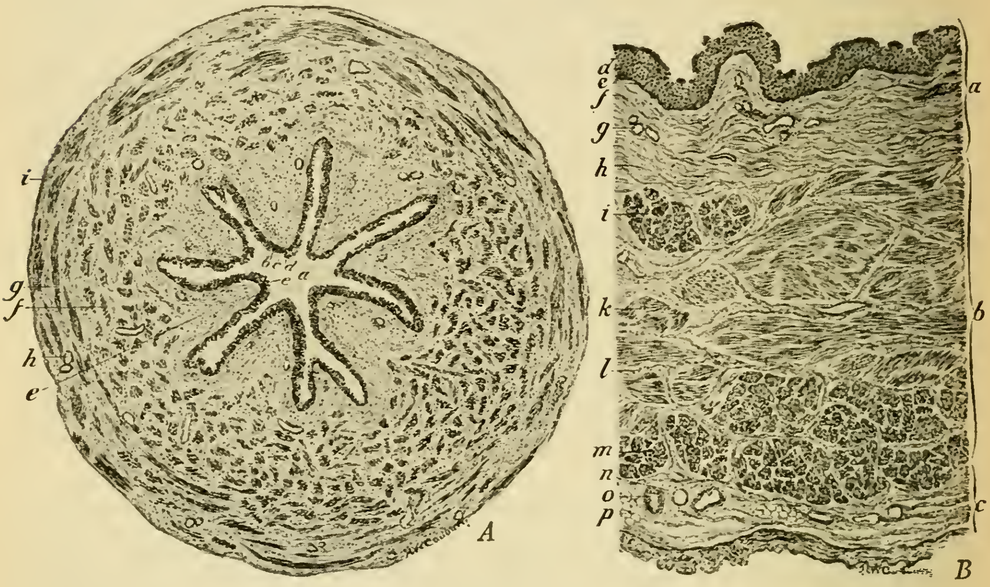


Fig. 200.

A, Cross-section of Human Ureter—*a*, Lumen; *b*, epithelium; *c*, basement membrane; *d*, longitudinal fold of mucosa; *e*, tunica propria; *f*, inner longitudinal muscle; *g*, outer circular muscle; *h*, vessels; *i*, fibrous coat. *B*, Cross-section of Segment of Human Bladder—***a***, Mucous coat; *b*, muscular coat; *c*, fibrous coat; *d* transitional epithelium; *e*, basement membrane; *f*, tunica propria; *g*, blood-vessels; *h*, white fibrous tissue; *i*, inner longitudinal muscle; *k*, middle circular muscle; *l*, white fibrous tissue; *m*, outer longitudinal muscle; *n*, venule; *o*, arteriole; *p*, adipose tissue.

The **muscle coat** consists of smooth muscle tissue arranged in definite layers. In the bulk of the ureter there are *two layers, inner longitudinal* and *outer circular.* The longitudinal layer is best developed in the first part of the tube and in the middle portion the circular fibers are most marked; in the lower part and *outer longitudinal layer* is added and this is well developed. Although this layer seems to be derived from the musculature of the bladder but it belongs distinctly to the ureter and is called the *ureter-sheath,* by Waldeyer. This layer is distinctly separated from the middle circular layer and from the fibrous coat. The muscle coat has a considerable quantity of areolar tissue between the muscle bundles.

The **fibrous coat** is a thin, distinct layer of white fibrous tissue that surround the tube. Even in that part of the ureter that passes through the bladder wall this coat maintains its identity and at the terminal part of the ureter blends with the fibrous portion of the mucosa.

At the ureteral orifice in the bladder the mucosa becomes continuous with that of the bladder. At this region the mucosa of the ureter, at the upper part of the orifice, projects in the form of a small fold called the *valve of the ureter.*

The *blood-vessels* of the ureter are numerous. The *arterial vessels* pass into the fibrous coat and from these capillaries pass to the superficial parts of the mucosa and glands and to the muscle coat. This blood is collected by the *venous channels* that have a corresponding course and then empty in the neighboring veins.

The *lymph* from the interstitial spaces is carried to plexuses of vessels that lie in the mucous, muscular and fibrous coats; these plexuses communicate with one another and the lymph is ultimately carried to the plexus in the fibrous coat; from here it is carried by efferent channels to the neighboring lymph nodes.

The *nerves* are from the *sympathetic system* and they form a ganglionated plexus in the fibrous coat. The *sensor fibers* form a plexus in the tunica propria and from this some fibers terminate in the deeper epithelial layers while others terminate in the areolar tissue in tufts of fine fibrils. The *motor fibers* pass to the muscle tissue of the tube and to the muscle of the vessels.

BLADDER

The **bladder** is a muscular sac that acts as a reservoir for the urine. It consists of *fundus* or *body*, and a small constricted portion, the *neck*, which continues as the urethra.

The **mucous** coat resembles that of the ureter in structure. The *transitional cells* vary according to the state of the bladder. When this organ is empty and contracted the cells are of the transitional variety. When the bladder is distended the surface cells flatten in order to assist in covering the extended surface. The superficial cells reproduce by amitosis and the deeper ones by mitosis. In urinary examination it is impossible to tell the cells of the pelvis, ureter and bladder from one another. The *tunica propria* consists of areolar tissue and contains some lymphoid tissue of the diffuse variety and even solitary nodules. Mucous glands are said by some to be present while others deny their presence. These so-called glands are probably evaginations of the epithelium that may be solid or hollow. As a *basement membrane* seems to be absent, delicate fibrils of the tunica propria and even capillaries are sometimes seen in the deeper layers of the epithelium.

The mucosa is of a reddish-pink color (due to the vascularity) soft and loosely attached to the muscle coat except at the *trigone;* this triangular area has for its apex the urethral orifice and for its basal angles the ureteral orifices. A line connecting the two orifices of the ureters is the base and this area is the *trigonum vesicæ.* In the empty and partially distended condition the mucosa is thrown into folds, except at the trigone, that are the *rugæ* of the bladder. These gradually smooth out under distension and when the organ is fully distended the mucosa is even. In all of the hollow organs that undergo considerable distension this is the case.

The **muscle coat** is composed of smooth muscle tissue but the layer formation is not so distinct as in the ureter. *Three layers* are described, *inner longitudinal*, *middle circular* and *outer longitudinal.* The *inner longitudinal layer* is described by some as belonging to the submucosa of the bladder as it is separated from the middle circular layer by a narrow band of areolar tissue, the so-called *submucosa.* These muscle fibers are really irregular scattered and do not form a distinct longitudinal layer. At the fundus of the bladder there is an additional layer of smaller and finer fibers called the *submucous muscle layer.* They probably represent a partially developed muscularis mucosæ and form the *internal sphincter muscle* of the bladder.

The *middle circular fibers* are not arranged in a distinct transverse manner but form a network especially in the upper part of the organ. In the lower part they are more distinctly circularly arranged and at the base of the bladder they disappear. Their place is taken by the submucous layer previously mentioned. The circular layer is thicker than the outer longitudinal layer.

The *outer longitudinal fibers* form a distinct layer on the ventral and dorsal surfaces of the organ; at the sides these fibers are more oblique in direction and interlace somewhat.

The **fibrous coat** is quite thin and poorly developed over the greater part of the bladder. Its fibers extend in between the muscle bundles and join the considerable white fibrous tissue of the muscle coat. About one-half of the bladder has a *serous covering* that represents a reflection of the peritoneum over the organ.

The muscular coat is so irregular in its thickness that in the distended organs parts of the wall are very thin. If these areas become so weak as to permit the mucosa and fibrosa to bulge the bladder becomes sacculated and the projections are each known as an *appendix vesicæ.*

The bladder receives its *blood-supply* from the superior and inferior vesical arteries and, in the female the uterine artery sends branches. These vessels form a network in the fibrous coat and from this branches extend to the muscle coat to form an extensive capillary plexus; other branches pass to the mucous (submucous of some) and form a plexus here, the branches of which supply the mucous coat. The blood is then collected into *venous channels* that form plexuses that are located in the three coats, with the exception of the trigone area. From these plexuses veins arise that carry the blood to the internal iliac veins, but do not accompany the arteries.

The *lymphatic vessels* are found in the muscle and fibrous coats and the trigone of the mucosa. The lymph of the intercellular spaces is carried to these plexuses, the muscle plexus emptying into the plexus in the fibrous coat. The efferents from the fibrous coat carry the lymph to the neighboring nodes.

The *nerves* are both *cerebrospinal* and *sympathetic.* The *former* are *motor* from the third and fourth sacral spinal nerves chiefly and *sensor* from the twelfth thoracic and first and second lumbars; the sympathetic nerves are from the hypogastric plexus. Both sets of fibers go to the pelvic plexus and from this other fibers pass to the bladder and form the vesical plexus. From this each half of the bladder is supplied independently. In the fibrous coat there are *ganglia* that are more numerous near the base of the bladder; fibers from these ganglia form a fine plexus in the muscle coat and the terminal fibers of this plexus supply the muscle fibers. There is another fine plexus in the mucous coat, fibers from which supply the neighboring muscle fibers and the epithelium of the deeper layers.

THE FEMALE URETHRA

The **female urethra** consists of *two coats,* **mucous** and **muscular.** This tube is shorter and of a wider caliber than in the male.

The **mucosa** consists of epithelium that is of two varieties; at the beginning of the tube the *transitional cells* of the bladder continue into it and are somewhat flattened. As the external urinary meatus is approached the epithelium changes to the *stratified squamous* variety that is continuous with that of the vestibule. Some describe a stratified columnar variety in the middle part of the tube. These cells rest upon the *tunica propria* that is usually papillated and also thrown into longitudinal folds. In the areolar tissue are found a few racemose mucous glands, the *glands of Littré.* Some tubular glands may be present near the bladder and these will contain structures that resemble the amyloid bodies of the male prostate gland. Near the external orifice are seen the ducts of the *periurethral glands.* The outer part of the tunica propria is loose and contains many large calibered venous channels that constitute *erectile tissue* sometimes called the *corpus spongiosum urethræ.*

The **muscle coat** consists of smooth muscle tissue arranged into incomplete *outer circular* and *inner longitudinal layers* separated from each other by an intermuscular layer of white fibrous tissue.

The longitudinal fibers are best marked at the distal end of the urethra and in the dorsal wall; the circular fibers are best marked at the proximal extremity where they tend to form an indistinct *sphincter muscle.* Some voluntary striated fibers are found in this muscle coat.

THE MALE URETHRA

The **male urethra** is more complex and differs in function from that of the female in not only carrying the urine but also the genital secretions. It is 18 to 20 cm. in length and is divided into three parts, **prostatic, membranous** and **penile portions.** The **prostatic part** lies within the prostate gland and measures about 3 cm. in length and in the resting condition the mucosa is thrown into longitudinal folds. It is the least distensible part of the tube. Along the dorsal wall is a permanent ridge called the *urethral crest* and on each side there is a longitudinal groove called the *prostatic sinus* in which are seen the numerous openings of the ducts of the prostatic glands. In the urethral crest there are *three openings* side by side; the *middle one* is the largest and represents the orifice of the *prostatic utricle.*

This is a blind pouch, the remnants of the fused distal extremities of the fetal ducts by Müller, representing the vagina of the female. This sac is from 6 to 12 mm. deep and is lined with *simple columnar*, or according to some simple ciliated cells. These rest upon a *basement membrane* outside of which is the *tunica propria* that contains considerable true erectile tissue and some smooth muscle fibers that are continuous with that of the urethral crest. In the side walls are the ejaculatory ducts and near the urethral orifice are some small glands that empty into the cavity of the sinus. It is said that when the crest is engorged with blood it prevents the passage of the semen backward into the bladder (Walker). On each side of the orifice of the utricle is seen the *opening of each ejaculatory duct.*

The **membranous part of the urethra** is about 18 mm. in length and lies between the layers of the triangular ligament. It connects the prostatic and spongy portions. It is the narrowest part and has the thinnest walls and is therefore most liable to rupture through the improper passage of urethral instruments. It is surrounded by smooth muscle and erectile tissues and upon each side is a gland of Cowper. On section the lumen is stellate.

The **penile, or spongy portion** is about 15 cm. in length and lies in the corpus spongiosum of the penis and is, therefore, surrounded by erectile tissue. Its caliber varies in its different parts and at its distal extremity, just within the external urinary meatus it is markedly dilated; this constitutes the *fossa navicularis.* In section the lumen is ⊥-shaped.

The **mucosa** consists of epithelium, basement membrane and tunica propria. The *epithelium* of the tree parts varies and although the following is a general description, variations are met with. In the *prostatic part* the cells are of the *transitional type* continued from the bladder. These cover the urethral crest and continue into the prostatic sinuses and ducts of the prostatic glands for a short distance. In the *membranous part* the epithelium changes to the *stratified columnar type.* In the *penile part* most of the cells are of the *simple columnar* variety, but the *fossa navicularis* is lined with *stratified squamous cells* that are continuous with those upon the surface of the glans penis. *Goblets cells* are also present. These cells rest upon a delicate basement membrane that is supported by the areolar tunica propria in which the elastic fibers are very numerous. This layer contains near the outer part, many anastomosing veins that connect with the cavernous spaces in the corpus spongiosum. In the tunica propria there are many small glands of the mucous type, these are the *urethral glands,* or *glands of Littré.* In addition there are many outpouchings of the mucosa forming the lacunæ the largest of which is in the fossa navicularis and is called the *lacuna magna.*

The **muscle tissue** is of the smooth variety. In the prostatic part the *outer circular fibers* are predominant and near the bladder end tend to form a sphincter. These fibers connect with the musculature of the prostate. The *inner longitudinal layer* is thin and continues into the membranous and penile portions. In the membranous part the muscle coat is thin and is reinforced by voluntary striated fibers that represent the *compressor urethræ muscle.* This tapers toward the prostatic and penile portion. In the penile part the muscle is all smooth and is found chiefly in the dorsal and lateral walls. It is mainly longitudinally directed and disappears before the glans is reached.

The *blood-vessels* are numerous. The *arteries* give off branches some of which form capillaries in the usual way; other branches are tortuous and gradually pass over into large dilated endothelial walled channels that are called *sinuses* and constitute the true erectile tissue. These are extensive cavernous spaces that lead into *venules* that conduct the blood from the organ. The ordinary capillaries supply the mucosa and the muscle tissue.

The *lymphatic vessels* of the urethra are chiefly in the mucosa; these receive the lymph from the interstitial spaces and the efferents carry the lymph to the abdominal nodes.

The *nerves* are derived from those of the clitoris or penis. They are both *cerebrospinal* and *sympathetic*. The cerebrospinal are *motor* and *sensor*, the *motor* going to the voluntary muscle and the *sensor* to the epithelium of the mucosa as free endings and to the tunica propria where the fibers terminate in the *genital corpuscles* and *Pacinian bodies*. The *sympathetic fibers* from the hypogastric plexus pass to the smooth muscle tissue of the vessels and the muscle coat of the urethra.

The various portions of the urinary system are lined by the following cells:

Kidney.	
Uriniferous Tubule:	
Renal Corpuscle	Simple squamous.
Neck	Simple squamous.
First Convoluted Tubule	Cuboidal to columnar.
Descending Limb	Simple squamous.
Loop of Henle	Simple squamous or low cuboidal.
Ascending Limb	Low cuboidal.
Second Convoluted Tubule	Cuboidal to columnar.
Arched Connecting Tubule	Cuboidal.
Straight Collecting Tubule	Columnar.
Papillary Ducts	Tall columnar.
Pelvis	Transitional.
Ureter	Transitional.
Bladder	Transitional.
Urethra. Female	Transitional. Stratified squamous.

MALE

FIRST PART (PROSTATIC)	Transitional.
SECOND PART (MEMBRANOUS)	Stratified columnar.
THIRD PART (SPONGY)	Simple columnar.
FOSSA NAVICULARIS	Stratified squamous.

ADRENAL

The **adrenal,** or **suprarenal body** is a *ductless gland.* It lies at the upper pole of the kidney, and is yellowish in color. Upon section, it shows a yellow external layer, and a dark centrum. Upon the ventral surface of each gland is an indentation called the *hilus* which permits the exit of several veins.

The organ is surrounded by a *capsule* of white fibrous connective tissue that contains a considerable quantity of smooth muscle tissue. From the internal surface of the capsule trabeculæ extend into the organs and anastomosing form the coarse framework of the structure. These trabeculæ contain some smooth muscle tissue. Within the network formed by the trabeculæ there is a delicate meshwork of *reticulum* that constitutes the finer framework and this supports the functionating epithelium, blood-vessels, nerves and lymph channels. This reticulum is connected to and derived from the trabecular framework. The arrangement of the trabeculæ differs in the various parts of the organ. Just beneath the capsule the trabeculæ anastomose at short intervals forming spaces that are approximately from 0.0125 to 0.02 mm. in diameter so that the epithelial cells are arranged here in ball-like masses constituting the zona glomerulosa. In some areas these glomeruli are wanting perhaps because the trabeculæ failed to form these spaces. Just within this zone the trabeculæ are straight and parallel to one another causing the cells to arrange themselves in columns, two cells wide. This is the zona fasciculata and is the widest zone of the cortex. At the end of this zone the trabeculæ again anastomose freely but irregularly so that the meshes here are more variable in extent and more irregular than in the glomerular zone. The cells in this inner zona reticularis are therefore arranged into anastomosing chains and form the narrowest and least distinct zone of the cortex. In the central part of the organ, the medulla, the trabecular arrangement is the most irregular of all. Here they course and anastomose in such a manner that some in places chains, in others glomeruli and groups are formed. In the stroma of the medulla considerable elastic tissue is said to occur.

The peripheral portion of the organ is the **cortex** and the arrangement of the parenchyma into its *three zones* is due to the direction taken by the trabeculæ. The divisions are the **zona glomerulosa, zona fasciculata** and **zona reticularis.**

The **zona glomerulosa** consists of groups of cells that measure from 0.0125 to 0.02 mm. in diameter. These groups may be spheroidal, or somewhat curved in form and this zone is two or three glomerules wide. In some places, however, the glomerules are absent and the zona fasciculata comes to the capsule. The groups are fairly widely separated from one another the intervening spaces being filled in with the trabeculæ, reticulum and the capillaries. The cells are mainly polyhedral, 12 to 20 microns in diameter, but in some animals they are columnar in shape and a central lumen may be apparent. The outlines of the cells are usually not distinct; the cytoplasm contains a large number of fine acidophilic granules and quite a few droplets of fat that assist in giving the yellowish color to the cortex. The spherical nuclei are rich in chromatin.

The **zona fasciculata** consists of comparatively long columns of cells that form the widest zone of the cortex. The cells of the innermost glomeruli may be continuous with the column cells. These columns, two cells wide, consist of polyhehral, or columnar cells, whose cell outline is distinct. In some cells the spherical nuclei are vesicular and in others they contain considerable chromatin. This condition seems to be in relation with the structure of the cytoplasm. In some columns the cytoplasm of the cells is finely granular (acidophilic) and the droplets of fat are extremely small. In such cells the nucleus (there may be two) are usually darkly staining. In other columns all of the cells show the cytoplasm to contain but few granules while the fat droplets are numerous and large. The nuclei are usually pale and vesicular. The cell outline not quite so distinct as in the other cells.

The **zona reticularis** consists of anastomosing chains of cells and although of the general form and size of the preceding differ in structure. The nucleus contains considerable chromatin while the cytoplasm contains very little fat. On the other hand the cytoplasm contains a large number of coarse granules of pigment. These granules are yellowish brown and are said to be present only in the adolescent and adult condition and also said to vary in different individuals. These are *chromaffin granules.*

In the fetus and at birth the large size of the adrenals is due to the excessive development of the inner part of the cortex. The cells contain no fat and this part is very vascular. This *fetal cortex* begins, shortly after birth, to show fatty degeneration of its cells so that by the end of the first year, usually, it is gone. The peripheral cells, however, are fat containing and form a very thin layer. From this the cortex, as seen later, is developed.

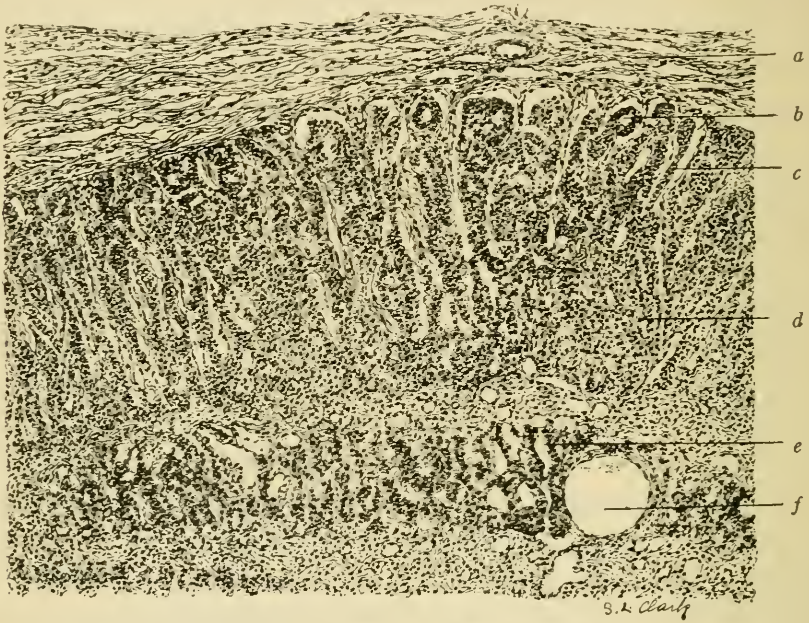


FIG. 201.—SECTION OF HUMAN ADRENAL.
a, Capsule; *b*, zona glomerulosa; *c*, zona fasciculata; *d*, zona reticularis; *e*, chromaffin cells of the medulla; *f*, medullary vein.

The **medulla** consists of epithelial cells that resemble those of the zona reticular closely. They are different in size and the smaller ones are arranged in anastomosing columns while the larger ones are arranged in groups. The *smaller cells* contain more fat and the nuclei do not stain so deeply. The *large cells* are polyhedral, their cytoplasm is finely granular (acidophilic) and the nuclei stain more readily. They are said to contain secretory canaliculi. In these cells there are also granules like those found in the cells of the reticularis. These *chromaffin granules* are supposed to be connected with the formation of the adrenalin and they stain deeply with chromium salts. These granules are also found in the hypophysis. In the reticulum of the medulla in addition to the blood-vessels isolated sympathetic nerve cells and small ganglia are found.

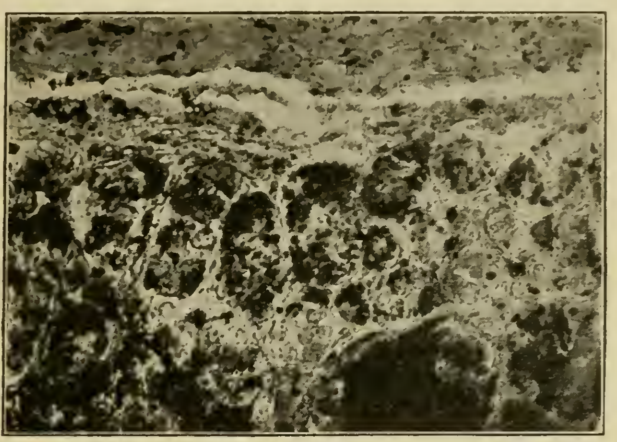


Fig. 202.—Fat Globules in the Cells of the Zona Glomerulosa of the Adrenal Gland Fixed in Osmic Acid. (Photograph. Obj. 16 mm., oc. 10 X.)

The *arteries* are from several sources and their branches form a plexus of vessel in the capsule of the organ. Some of the branches of this plexus supply the capsule; others, the *cortical arteries*, soon form a dense plexus of capillaries of the sinusoidal type around the cells of the various zones. The endothelium of the capillaries is in direct contact with the epithelium of the organ as in the liver. In the reticularis the sinusoids are larger and their anastomoses more frequent and from this plexus *venules* arise that pass directly to the central veins of the medulla. Other branches from the capsular plexus are the *medullary arteries*. These pass, without branching, through the cortex straight to the medulla where they form a meshwork of sinusoids around the cell-groups. In some places, it is said, the endothelium is absent and the medullary cells are bathed directly in blood. The presence of the sinusoids, especially those of the open type, facilitates the transfer of the internal secretion, *adrenalin*, from the cells directly to the blood. It is also stated that diverticula of the sinusoids penetrate the cell chains and groups. From the medullary plexus of sinusoids the blood is collected by a few *venules* that ultimately unite to form the two, to four *medullary veins*. These leave the organ at the hilus. The veins of the capsule do not join the central veins.

Lymph vessels are numerous. One plexus lies in the medulla and another in the capsule. These two are connected by vessels that pass through the cortex. The lymph from the lymph spaces in the medulla enters the plexus and from this the lymph of the cortex and that of the medula is carried by efferent channels through the hilus to near lymph nodes. The lymph of part of the cortex and the capsule is carried by efferents from the capsular plexus to neighboring nodes.

The *nerves* are *sympathetic* and are derived from the solar and renal plexuses, but some possibly come from the phrenic and vagal nerves also. These nerves form a plexus in the capsule and from this fibers are sent to the cortex and others to the medulla. The latter form a plexus in the medulla. The cortical fibers are for the blood-vessel around which they form plexuses. In the medulla numerous *ganglion cells* and *ganglia* are seen. The fibers of this plexus supply the vessels here as well as the epithelium. The fibers to the latter terminate upon and between the cells in little knobs or fine fibrils.

CHAPTER XIII

THE MALE GENITAL SYSTEM

The **male generative organs** form a very complex system. They comprise the **testes, epididymi, vasa deferentia, seminal vesicles, ejaculatory ducts, prostate, glands of Cowper** and the **penis.**

In the human being and in most mammals the testes lie outside of the body in a sac-like structure called the **scrotum.** This consists of a number of layers. Externally it is covered by the *skin* that consists of stratified squamous cells resting upon a basement membrane and papillated derma. The skin is darker in color than in common, in the Caucasian, due to the presence of pigment in the Malpighian layer. It contains numerous sweat and sebaceous glands, the latter being connected with the crisp curly hairs that are present. The skin is thrown into rugous folds and in the midline there is a ridge-like elevation that is continuous with a like ridge upon the under surface of the penis and the skin of the perineum. This is the *raphê* and indicates the line of union of the fetal genital folds. Beneath the skin is the *dartos fascia.* This consists of fibro-elastic tissue containing a considerable quantity of smooth muscle tissue. The elastic tissue is abundant as is also the muscle tissue. This dartos forms the *septum* that divides the scrotum into two separate compartments. The muscle tissue is peculiar in that it does not respond to electrical stimuli as ordinary smooth muscle does. Cold, or extreme warmth, causes it to contract causing the scrotum to become shorter and thicker; moderate warmth causes the muscle tissue to relax and the scrotum becomes elongated and thinner and that portion between the level of the testes and the attachment to the body is drawn out into a neck-like part. The left testicle is usually a little more dependent than the right. Internal to the dartos fascia are three other layers of fascia composed of white fibrous tissue and containing some voluntary striated muscle, the

Cremaster muscle. These are derived from the abdominal wall during the formation of the scrotum and the descent of the testes. Each compartment is lined by a *serous membrane*, the *parietal layer of the tunica vaginalis testis*, that is derived from the peritoneum. This consists of a single layer of endothelial cells resting upon the fibro-elastic subendothelial connective tissue. It is continuous with the serous membrane, *visceral layer*, that invests each testis. Between these two layers is a serous space in which the testis moves.

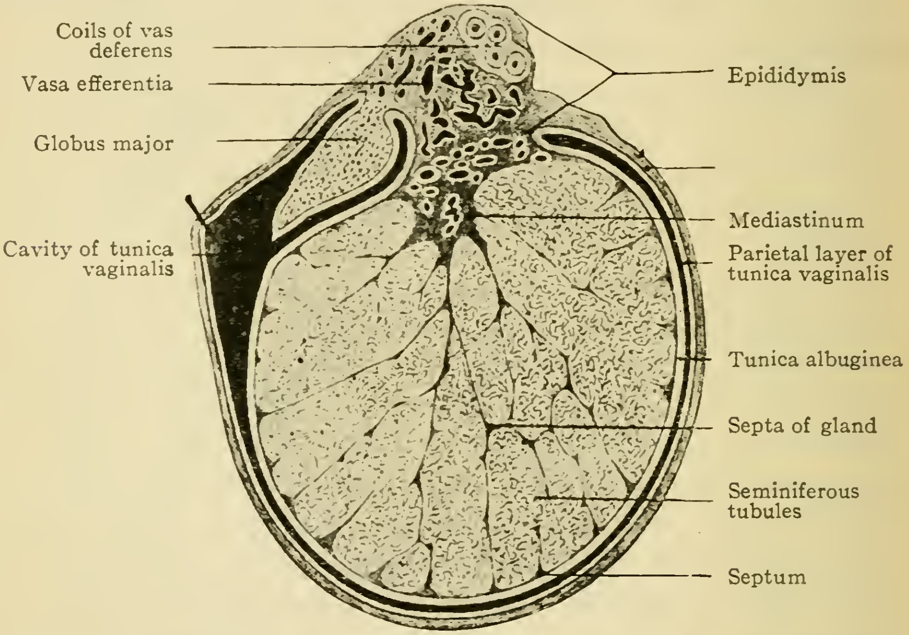

Coils of vas deferens
Vasa efferentia
Globus major
Cavity of tunica vaginalis
Epididymis
Mediastinum
Parietal layer of tunica vaginalis
Tunica albuginea
Septa of gland
Seminiferous tubules
Septum

FIG. 203.—CROSS-SECTION OF HUMAN TESTIS AND EPIDIDYMIS, (*Eberth.*)

The **testis** is another *compound tubular* gland. It is surrounded by an unusually thick **capsule** called the **tunica albuginea,** which is composed of bundles of white fibrous tissue that interlace so as to form a very tough and prominent covering. It holds the substance of the testis under pressure for if the capsule be nicked the parachyma bulge out through the incision. From its inner surface, prolongations, or *trabeculæ*, pass into the center of the organ to divide it irregularly into compartments. These trabeculæ all converge at the dorsal portion of the organ, where the capsule is very thick, forming, at this point, a thickened mass called the **corpus Highmori** or **mediastinum testis.** Here a number of tubules, to be described later, are found.

The *compartments* correspond to the *lobules* of other glands and the septa to the interlobular connective tissue that forms a complete wall around each lobule. In the lobules is the interstitial connective tissue that consists of a delicate network of loose areolar tissue.

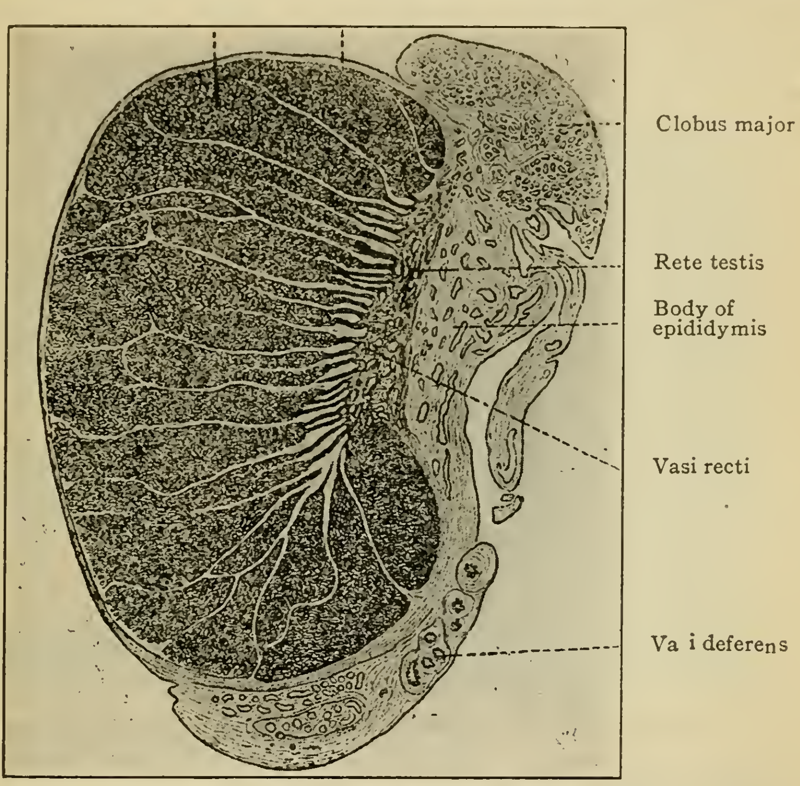


Fig. 204.—Longitudinal Section of Human Testis and Epididymis. (*After Böhm and Davidoff.*)

The meshes are large because the contained seminiferous tubules are unusually large. The elastic tissue is abundant and many fibers encircle the tubules forming a part of their tunica propria. This *interstitial tissue* supports the tubule, blood-vessels, nerves and some cells called the *interstitial cells of Leydig.* These are scattered or arranged in small groups and in some animals they are very numerous forming large masses, or are arranged in anastomosing chains. They are large, polyhedral elements the coarsely granular cytoplasm of which contains crystalloids and fat globules and a double centrosome. Elongated, prismatic crystals have also been found but their origin and nature are as yet unknown. The crystalloids are said to be mitochondria. The fat reacts readily to osmic acid. The nucleus stains well, is eccentrically placed and contains a nucleolus. These cells are said to be derived from the flattened interstitial connective-tissue cells by a direct modification of these. These cells are fairly numerous in the sexually active male but their number is also subject to individual variation. In those testes that are not actively functional these cells are more numerous and usually contain more fat.

The interstitial cells are most numerous in the fetus, diminish in early childhood and increase again at puberty and are fairly numerous during the sexual life of the individual. These cells manufacture an *internal secretion* that seems to control sexual impulses and secondary sexual characteristics. In transplantation experiments by Steinach, the transplanted ovaries or testes showed degenerative changes in the ovarian follicles or seminiferous tubules but the interstitial cells were increased in number. Secondary sexual characteristics were developed. In animals that have regular "seasons" these cells are most prominent at the periods of sexual activity. In hybrids that are incapable of reproducing the testes contain great numbers of interstitial cells and the sex cells are poorly developed and show degeneration signs. Such animals, although incapable of reproduction, experience "heat."

The **mediastinum testis** occupies about one-third of the dorsal border of the organ. It consists of the septa that comes from the capsule, after forming the compartments; the bundles of fibers form a coarse meshwork in which is supported the blood-vessels, lymph channels, nerves and the anastomosing ducts that form the excretory ducts. It corresponds to the hilus as it is here that the vessels and ducts enter or leave.

The **tunica vaginalis testis** is a **serous membrane** that at one time, was continuous with the peritoneum. It covers almost the entire organ, and is attached to the tunica albuginea, and constitutes the *visceral layer of the tunica vaginalis.* It is reflected over the inner surface of the scrotum as the *parietal layer.* Some writers consider this membrane part of the tunica albuginea, and describe it as such, but as it is *genetically different*, it should be considered a separate covering.

The **parenchyma** of the testicle is made up of **tubules,** which, like those of the kidney, are very convoluted, and consist of *secretory* and *conductive* portions. These tubules are the **seminiferous tubules,** and are collected into groups which correspond to lobules that number from 100 to 150.

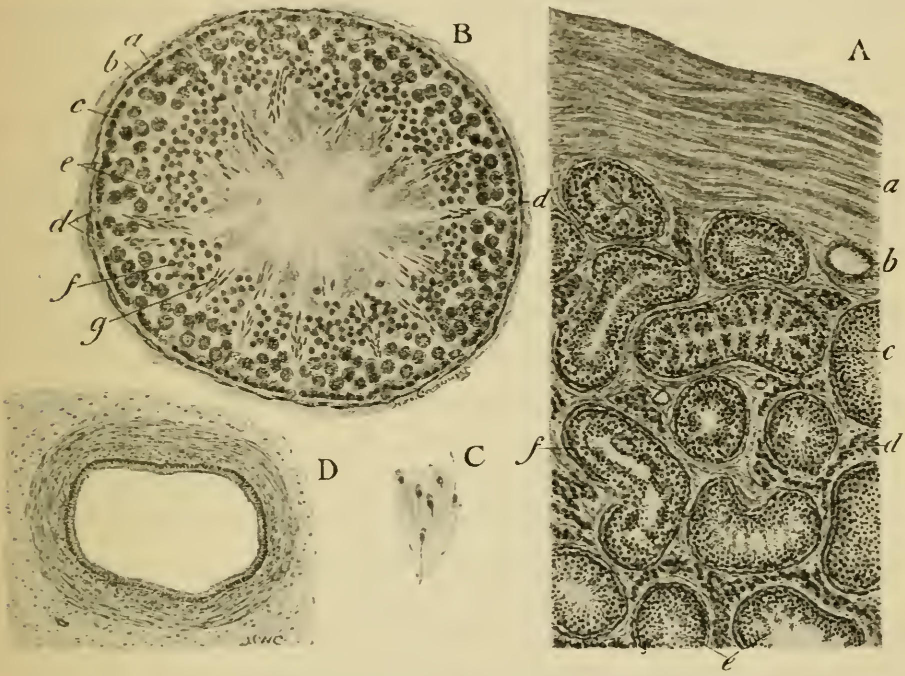


FIG. 205.—HUMAN TESTICLE.

A, Peripheral portion of the testicle showing the capsule and tubules—*a*, Tunica albuginea; *b*, blood-vessel; *c*, membrana propria of tubule; *d*, interstitial cells; *e*, spermiogenetic cells; *f*, lumen of longitudinal tubule. B, Single seminiferous tubule highly magnified—*a*, Tunica propria; *b*, basement membrane; *c*, spermiogonia; *d*, cells of Sertoli; *e*, mother and daughter cells; *f*, spermids; *g*, spermia. C, Spermia highly magnified. D, Tubule of the epididymis.

The seminiferous tubules are said to end blindly underneath the capsule at the base of the compartment although Bremer states that they may anastomose or branch.

In rabbits the two tubules of a lobule are continuous like a U, or one limb may be in one lobule and the other in a neighboring lobule; again the anastomoses may be more complex. These anastomoses, according to Curtis, are most numerous in the rabbit, less so in the dog and uncommon in the mouse. There are said to be three to four convoluted tubules in each compartment, or about 600 in the testicle of man. According to Lauth there are 800 to 900 seminiferous tubules in each testis.

When straightened each measures about 50 to 80 cm. in length; the length of them all together is given as 650 to 800 meters. At the apex of a compartment these convoluted tubules unite to form a smaller number of straight tubules that are *conductive* in function. These are the **vasi recti,** which pass into the mediastinum, where they anastomose to form a network called the **rete testis.** In the upper portion of the mediastinum, these tubules join to form a few, ten to fifteen, vessels that pass toward the edge of the corpus Highmori as the **vasa efferentia.** As these leave the testicle, they become convoluted and dilated into cone-shaped structures called the **coni vasculosa** or **globus major**, of the epididymis. The **coni vasculosa** unite to form a *single* tubule that runs a very convoluted course, forming a narrow continuation of the above, called the **body** of the epididymis. At the the lower pole of the testicle, the mass formed by the continuation of the body is somewhat larger, and is named the **globus minor.** The tubule that continues from this point into the abdomen is called the **vas deferens.**

The **seminiferous tubules** are from 140 to 200 microns in diameter, and form the bulk of the testicle. The square surface of each tubule is said to be 1784 sq. mm. Each consists of a small amount of tunica propria, and a *basement membrane,* upon which are found two to three layers of cells. The *basement membrane* is thin and delicate and rests upon the relatively thick tunic propria. This measures about 7 to 10 microns in thickness and consists of lamellæ; the inner ones are closely arranged and the outer ones are looser forming a meshwork in which most of the fibers have a circular direction. The elastic tissue of the intertubular region contributes numerous fibers to this network. The cells of the tunica propria are flattened elements. The basal layer of the epithelial cells in the tubules consists of two varieties, the **spermiogonia,** which are the more numerous, and the **sustentacular cells,** or **columns of Sertoli.** These cells vary according to the secretory activity of the organ.

Before puberty the basal cells are regular while the other cells are polyhedral and practically fill the tubule, occluding the lumen. Some spermiogonia are noted. After puberty the various tubules are not all in the same stages of spermiogenesis. In those tubules in which spermia are fully developed three layers of cells are seen; (*a*) *basal cells*; (*b*) large, clear *spermiocytes* derived from the basal cells and these spermiocytes increase by their own mitosis; (*c*) *spermids*, smaller cells that become spermia. The spermids are derived from the spermiocytes by mitosis.

The *basal cells* comprise the spermiogonia and the cells of Sertoli. The spermiogia are fairly large cells but usually not so large as the spermiocytes. They form a single layer along the basement membrane with the Sertoli cells at frequent intervals. The cytoplasm is finely granular and stains lightly. The nucleus is large, stains deeply and mitotic figures are numerous. These cells by mitosis give rise to two cells one of which remains as a basal cell and the other one becomes a spermiocyte of the second layer.

The *sustentacular cells*, or *cells of Sertoli* are seen at fairly regular intervals along the basement membrane and their appearance varies with the stage of secretory activity of the tubule. In the resting stage each is a rather tall pyramidal cell with the base resting upon the basement membrane. The cytoplasm contains pigment, crystalloids, lipoid granules and fat droplets. The origin and function of the crystalloids is as yet unknown. The nucleus is located in the basal portion of the cells, contains little chromatin but presents several chromatic nuclei. As these cells apparently nourish the spermids during their transformation into spermia they have been called *trophocytes*. They reproduce by the direct method. In the stage of secretory activity these cells increase in size and extend through the thickness of the epithelial layer of the tubule. At that time from four to eight spermids become attached to one cell and as their transformation continues these spermids become inbedded in the cytoplasm of the sustentacular cell. This mass of cells is then called a *spermioblast*.

The **spermatozoön**, or **spermium**, consists of three main parts, **head, middle-piece,** and **tail,** and measures 52 to 62 microns in length (Krause).

The **head** is somewhat pear-shaped when viewed from the side and is 4 to 5 microns long and 2 to 3 microns wide and 1 to 2 microns thick. It consists of the condensed chromatin of the spermid constituting 11 or 12 chromosomes. It is surrounded by a delicate layer of protoplasm, the envelop, or *galea capitis*. In some mammals a little body is seen at the front part of the head just beneath the enveloping protoplasm; this is the *acrosome* (*perforatorium*) and it represents the attraction sphere of a centrosome. This end of the spermium represents, apparently, a cutting edge, and in some lower forms it possesses a spiral or barbed projection that assists in the entrance of the spermium into the ovum.

The **middle-piece,** or **connecting piece,** is composed of several portions, the **end-knob, axial fiber, spiral fiber** and **envelop.** The **end-knob** connects the head with the middle-piece and is also called the **neck.** Here is seen the divided centrosome, one part of which becomes a flattened mass at the junction of head and middle-piece; the other elongates into the **axial fiber** with its front end enlarged to a disc-like mass that ultimately separates from the axial fiber to surround it as a darkly staining ring. Surrounding the axial fiber is a delicate **spiral filament** that is probably derived from the mitochondria. This filament is not distinct in the spermia of man. The **envelop** is a thin layer of protoplasm that surrounds the middle-piece and is continued over the head and tail portions of the spermium.

The **tail** consists of **axial fiber** and **envelop.** The **axial fiber** is the continuation of the axial fiber of the middle-piece, but is not so prominent. It represents an elongated centrosome. It forms the motor portion of the organism and its origin from a centrosome is not difficult to understand when we consider that in ameboid, flagellated and ciliated cells the centrosome presides over the property of motion. It is about 5 microns longer than the envelop. The **envelop** represents a thin protoplasmic covering of the axial fiber and is continuous with that of the middle-piece. The tail is about 41 to 52 microns long and about 1 micron in diameter.

Abnormal forms of spermia are found such as double-tailed, split-tailed, four-tailed, double-headed, giant and dwarf. These defective spermia are thought to be due to a general weakening of the body from illness, alcohol, drugs and coffee.

Spermiogenesis is that peculiar change by which **spermia** are formed from cells several generations removed from the **spermiogonia,** or original cells. The male somatic cell is said to contain twenty-three chromosomes.

The spermiogonia represent the primordial cells. They reproduce rapidly, one of each of the daughter cells remains at the basement membrane to continue the cells and the other one is crowded with the cells from other spermiogonia to form the other layers of the tubule. These latter cells are the spermiocytes. A period or rest and growth intervenes and the spermiocytes increase in size until they are quite a bit larger than the spermiogonia. Then *maturation* occurs. These primary spermiocytes prepare for mitotic division but instead of twenty-three chromosomes (*diploid number*) forming *only twelve* are formed. This is said to be due to the *fusion by pairs* of the original twenty-three and the twelve constitute the

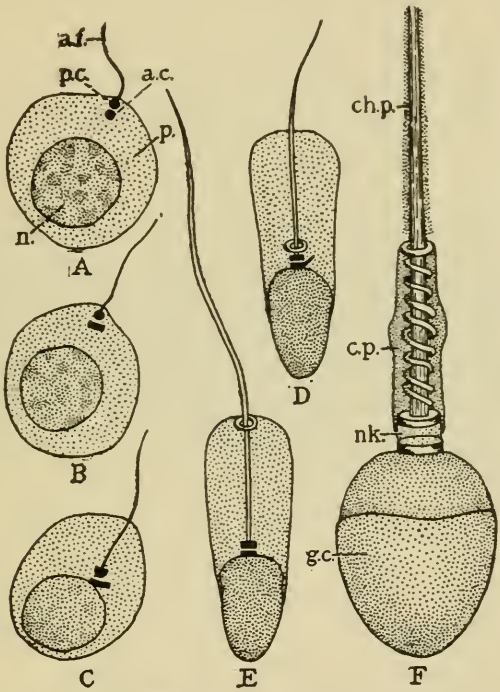


FIG. 206.—DIAGRAM OF THE DEVELOPMENT OF SPERMIA. (*Stöhr after Meves.*)

a.c., Anterior centrosome; *a.f.*, axial filament; *c.p.*, middle piece; *ch.p.*, tail; *n*, nucleus; *nk*, neck; *p*, protoplasm; *p.c.*, posterior centrosome.

haploid number. One of the twelve is a single chromosome, it having no mate in the fusion. In some animals the double form is apparent after the fusion. In the formation of the equatorial plate, or monaster, eleven of these chromosome split longitudinally and the unmated chromosome remains whole. This is the **X Chromosome.** When the cytoplasm divides eleven of these daughter chromosomes pass into one daughter cell and the other eleven and the undivided (**X**) chromosome pass into the other daughter cell. These secondary spermiocytes are about one-half the size of the primary spermiocyte and do not rest and grow to any extent but soon divide. As each daughter cell divides all of the chromosomes split longitudinally (including the **X** chromosome) so that the nuclear spindle of one-half of these daughter cells contains *twenty-two daughter chromosomes* and the other half of the daughter cells contain *twenty-four daughter chromosomes.* When the cytoplasmic division is complete the four granddaughter cells, or *spermids*, are of two classes; *two* possess *eleven chromosomes* and *two* possess *twelve* chromosomes. Each spermid becomes a *spermium*, or *spermatozoön* and if one containing eleven chromosomes fertilizes an ovum the offspring will be a *male.* If one containing twelve chromosomes fertilizes an ovum the offspring will be a *female.* The extra chromosome is the *sex determinant.*

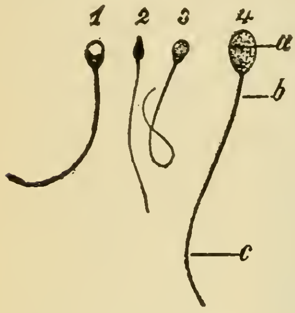


Fig. 207.—Spermia.
1, 2, 3, Human spermia: 1, Surface view; 2, side view; 3, looped seminal filament. 4, Spermium of a bullock: *a*, Head; *b*, middle piece; *c*, tail.

In the formation of spermia, the spermids are of the most importance. According to some authors, the nucleus forms the whole organism, while others hold the head and middle-piece are of nuclear origin, and the tail protoplasmic. These cells become crowded or drawn to the columns of Sertoli, to which they apparently attach themselves. At the same time, the shape of the cell becomes modified by elongation. The *chromatin* of the nucleus becomes denser and migrates toward the attached, or *peripheral end*, while the protoplasm draws toward the *central end.* At the attached, or peripheral end, the nucleus has a small prominence developed that indicates the *future head.* The protoplasm becomes clear and draws centrally, forming a slender vesicle, in the middle of which a delicate line appears. This line joins the head, and, growing backward, breaks through the cytoplasmic membrane to form the **tail** of the spermium.

The **centrosomes,** usually two in number, become different in shape; the attraction sphere of the *smaller* passes to the head of the spermium to become the **acrosome.** The *smaller* centrosome then becomes disc-shaped and attaches itself to head at its junction with the middle-piece; the *larger* is cone-shaped, and differentiates into two portions, the *larger* of which passes toward the nucleus (head), and develops a flattened extremity just behind the preceding centrosome; the remainder elongates into the axial fiber of the middle-piece and tail. The **envelop** is held to be cytoplasmic in origin.

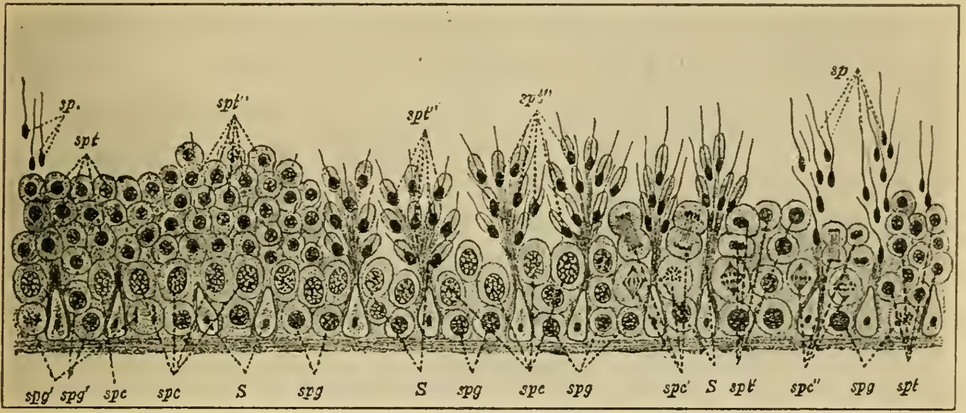


FIG. 208.—DIAGRAM OF THE PROCESS OF SPERMIOGENESIS IN A LONGITUDINAL SECTION OF A SEMINIFEROUS TUBULE.

sp, spermia; *S*, cell of Sertoli; *spg*, spermiogonia; *spg'*, same in mitosis; *spc*, spermiocytes; *spc'*, same in mitosis; *spt*, spermids; *spt''*, spermiocytes changing to spermia. (*Sobotta.*)

As the spermia continue to develop, the column of Sertoli increases in length, and when development is complete, the organisms lie in the lumen of the tubule. The column of Sertoli, with the attached spermids, is called a **spermioblast.** Loisel believes that these columns secrete a substance that attracts the spermids (*positive chemotaxis*).

The **semen** consists principally of spermia suspended in a fluid derived from the various portions of the genital tract. It is a viscid, whitish, opalescent fluid of an alkaline reaction and characteristic odor. According to Lode each cubic millimeter of semen contains 60,800 spermia; an entire ejaculate of about 3370 cu. mm. contains about 200,000,000 spermia. During life it is stated that about 340 billions are formed or about 850 million for each ovum. The spermia are practically *amotile* until mixed with the secretion of the prostate, when they become actively motile. Beside the *prostatic fluid* other secretion is added by the seminal vesicles, glands of Cowper and urethral glands (Littré). In addition to the spermia, *crystals* and *amyloid bodies* from the prostate, *fat globules* and *epithelial cells* are seen in the semen.

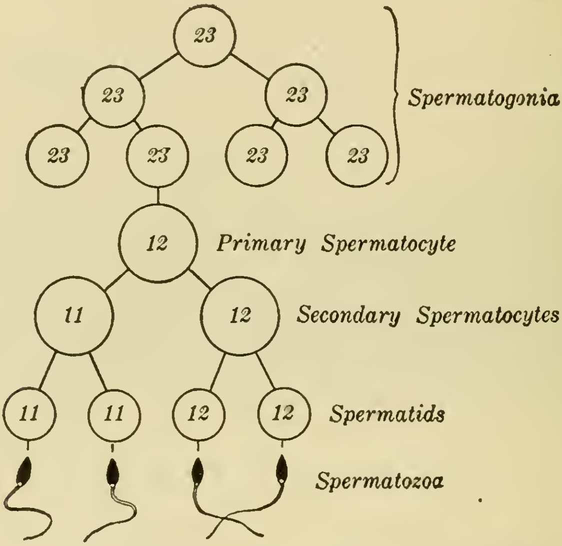


FIG. 209.—DIAGRAM OF THE CELL DIVISIONS IN SPERMATOGENESIS. The figures indicate the number of chromosomes found in the cells of certain grasshoppers. (*Lewis and Stöhr.*)

Motility may be exhibited by the spermia twenty-four hours after death. They have been kept alive for two weeks, under proper conditions, and this may readily occur in the female genital tract. Water, acids and metallic salts cause cessation of action, while alkaline and normal salt solutions aid it. Batelli, in 1902, found by experiments that the spermia travel better against than with the current although Lott (1872) and Hensen (1876) stated that they swim against the current. The movement depends upon the strength of the current. The spermia move at the rate of about 60 microns per second.

Motile spermia have been found in the testicle three days after execution. They have been found in the vagina twelve to seventeen days after copulation (Bassi) while Duhrsen and Zweifel have found living spermia in diseased oviducts four and one-half weeks after coition. In one to two hours after coition the spermia are in the oviduct.

The **excretory system** starts with the **tubuli recti.** These lie in the apices of the compartments and each is the direct continuation of the convoluted seminiferous tubules but is much smaller in diameter. Each is lined with *simple squamous epithelial cells* that rest upon a *basement membrane* that is supported by a delicate *tunica propria* that is continuous with the interstitial tissue of the lobule. Each is about 25 to 50 microns in diameter and passes out of the lobule to form the next part of the excretory system. They are the same in number as the seminiferous tubules.

The **rete testis** is made up of the anastomosing tubuli recti and lies in the mediastinum testis. These tubules have a larger and more irregular diameter than the foregoing tubules and are lined with *simple squamous*, or *cuboidal cells* that rest upon a *basement membrane* and *tunica propria.*

Along the dorsal and upper part of the mediastinum the tubules of the reti testi unite to form ten to fifteen tubules that constitute the **vasa efferentia,** or **ductuli efferentes.** They are about 0.5 mm. in diameter. The lining cells are peculiar in that in some areas it is *simple ciliated* and in others *nonciliated.* The ciliated cells are low and the cytoplasm contains fine granules that are acidophilic in reaction. The nucleus is basally placed. The nonciliated cells are columnar or polyhedral cells that are usually collected into groups. The cytoplasm is clear and the nucleus stains well. They seem to represent secreting cells of some sort. Beneath the basement membrane is a tunica propria containing a considerable quantity of circularly arranged smooth muscle tissue.

The **epididymis** consists of a mass of convoluted tubules that lies outside of the testicle. It is divided into three portions, the **globus major,** or **head,** the **body,** and the **globus minor** or **tail.** The

globus major consists of ten to fifteen large, cone-shaped tubules that are very convoluted. These tubules are the continuations of the vasa efferentia. The cilia are the largest in the body. The **body** and **tail** consist of a single long tubule that is very convoluted; if straightened it would measure 19 to 20 feet in length.

The epididymis is surrounded by a dense sheath, or capsule of white fibrous tissue that divides it into compartments. In the globus major, the tubules in a compartment represent the convolutions of one of the coni vasculosa.

The tubules are lined by *statified ciliated cells* that rest upon a basement membrane, outside of which is a distinct tunica propria. The ciliated cells of the coni vasculosi and upper part of the body of the epididymis are said to be true ciliated cells while the remainder are said not to be. In these latter cells the protoplasmic processes of the cilia, within the cytoplasm of the cell, all converge to one point and do not have the *basal particles*. In the true cilia cells the intracellular portion of each cilium is separate and distinct and where it ends in the cytoplasm it has two little bodies, called *basal particles*, attached to it. These particles are probably of centrosomic origin. External to this are two layers of smooth muscle tissue, one circularly, and the other (thin) longitudinally arranged.

The *arteries* pass into the mediastinum and divide into branches some of which pass into the interstitial tissue of the lobules and form plexuses of capillaries around the tubules and others pass in the septa to the inner surface of the capsule which they supply. The arteries are thin-walled. The blood is collected by the *venules* that have a corresponding course and carry the blood from the compartments to the mediastinum and the spermatic cord. Here the veins branch and anastomose freely forming the *pampiniform plexus of veins* from which one vein, the *spermatic*, carries the blood into the abdominal cavity. The epididymis receives branches from the spermatic artery as it passes into the mediastinum. The capillaries ramify the organ and the venous channels return the blood to the pampiniform plexus.

The *lympathic vessels* form plexuses under the tunica vaginalis, under the tunica albuginea and in the interstitial tissue of the lobules. The efferents from the first two plexuses follow the vessels in the septa to the mediastinum and join the efferent from the lobules. The lymph spaces in the lobules pass the lymph to large sinus-like channels in the interstitial tissue and the efferents carry the lymph to the mediastinum. Here all of the efferents follow the veins to the spermatic cord and along this to the iliac nodes of the abdominal cavity.

The *nerves* are of the *sympathetic* type and follow the blood-vessels which they supply. Other branches are said to enter the lobules and end in relation with the epithelial cells. The branches that supply the epididymis may have ganglia connected with them.

THE VAS DEFERENS

The **vas deferens** connects the testicle with the urethra. It passes into the body through the inguinal canal, and is accompanied, to the internal ring, by the spermatic artery and vein, the deferential artery, pampiniform plexus of veins, cremaster muscle and fibrous connective tissue. These form the **spermatic cord.** At the internal ring the vas continues by itself to the under surface of the bladder and near its termination is considerably dilated; this part is called the *ampulla.*

The **vas,** or **ductus deferens,** consists of *three coats,* **mucous, muscle** and **fibrous.**

The **mucous coat** consists of epithelial cells, basement membrane and tunica propria. The epithelial cells of the first part are of the *stratified ciliated* variety a continuation of those lining the epididymis. The remaining portion is lined with stratified columnar cells. The *basement membrane* is thin and rests upon the areolar *tunica propria.* The mucosa is thrown into longitudinal folds which are larger and more numerous in the ampulla.

The **muscle coat** consists of *three layers* of smooth muscle fibers, *inner longitudinal, middle circular* and *outer longitudinal.* This is usually a thick coat and at times the circular muscle fibers are not well disposed but run obliquely and interlace with the bundles of the other layers.

The **fibrous coat** consists of a thin layer of white fibrous tissue that covers the muscle coat and sends in fibers between the muscle bundles.

The vas is about 45 cm. in length but the first 15 cm. are convoluted or coiled into a small mass at the end of the epididymis. The remainder runs practically a straight course. The diameter is 2 to 3 mm. and the lumen in general is small. The diameter of the ampulla is 6 to 8 mm. and the lumen is proportionately large.

THE SEMINAL VESICLES

The **seminal vesicles** lie beneath the bladder, and empty into the vas through the **seminal ducts.** They consist of three coats, **mucous, muscular** and **fibrous.**

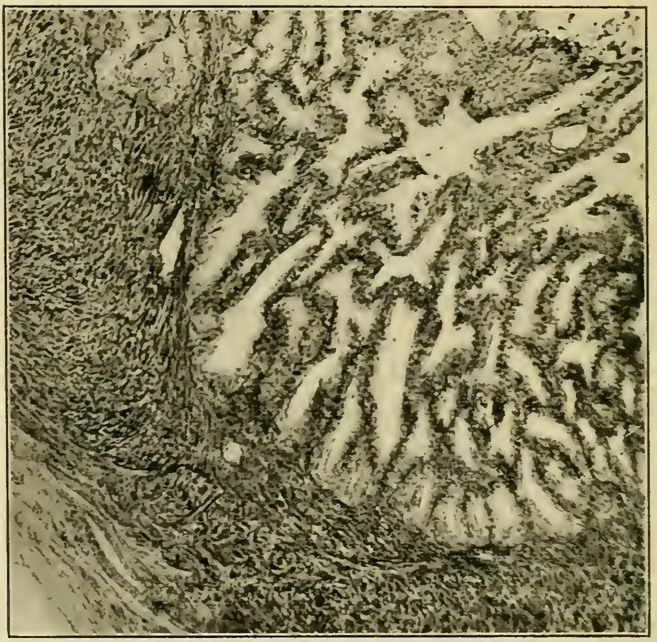


Fig. 210.—Section of the Human Seminal Vesicle. (Photograph. Obj. 16 mm., oc. 5 ×.)

The *epithelial cells* are of the *simple columnar* variety though pseudostratified cells, or two layers of elements may be seen. The cytoplasm of these cells usually contains a considerable quanity of yellowish pigment granules that are characteristic for this organ. These are probably secretory granules and with the desquamated cells constitute a part of the secretion of the organ. These cells rest upon a thin *basement membrane* that lies upon the fibro-elastic *tunica propria.* The mucosa is thrown into a great many folds or rugæ that run in all directions connecting with one another so that sections of the organ sometimes have a honeycomb appearance. Small areas of the mucosa may give the appearance of enclosed glands.

The **muscle coat** consists of smooth muscle fibers arranged as *inner circular* and *outer longitudinal layers.* The entire coat is said to be thinner than the corresponding coat of the vas.

The **fibrous coat** is a thin layer of white fibrous tissue and besides supporting the muscle coat it bridges over the gaps between the coils of the seminal vesicle. These organs act as reservoirs for spermia, at times, besides secreting a fluid that helps to make up the semen.

The **ejaculatory duct** is really the continuation of the vas but apparently is formed by the junction of the vas and the duct from the seminal vesicle. It has a thinner wall than the seminal vesicle and is about 18 mm. in length. It passes through the substance of the prostate gland and opens into the urethra in the urethral crest. It consists of *three coats.*

The **mucous coat** consists of *simple columnar cells* that rest upon a *basement membrane* and *tunica propria.* The latter is thrown into folds so that the mucosa has an irregular appearance. The **muscle coat** consists of smooth muscle tissue, chiefly longitudinally arranged and is thin. In the prostate this muscle blends with that of the prostatic trabeculæ. At the urethral extremity the lining cells are of the transitional variety.

THE PROSTATE GLAND

The **prostate** is a pyramidal organ that is situated so that the middle of its base is opposite the urethral orifice of the bladder; as a result the urethra traverses the prostate from base to apex. It is pierced on each side by the ejaculatory ducts as they pass through the organ to the urethral crest. Some call it a branched tubular and others a compound tubuloalveolar gland. It really consists of thirty to fifty little branched tubular glands, sometimes referred to as lobules. The organ is surrounded by a thin layer of white fibrous connective tissue beneath which is the *true capsule* that consists of *smooth muscle tissue.* This forms a very thick layer and from its deep surface tapering trabeculæ of smooth muscle pass toward the urethra and divide the prostate into compartments in which are the glands. These trabeculæ contain also some white fibrous tissue which continues into the lubules and forms a reticulum for the support of the gland tubules and the vessels and nerves. The smooth muscle tissue is not found around the tubules. The central ends of the trabeculæ blend with the muscle tissue of the urethra. The trabeculæ form about thirty to fifty lobules that represent the number of glands. The smooth muscle tissue of the intertubular stroma may be in the form of isolated fibers or small bundles. Connective-tissue cells are numerous.

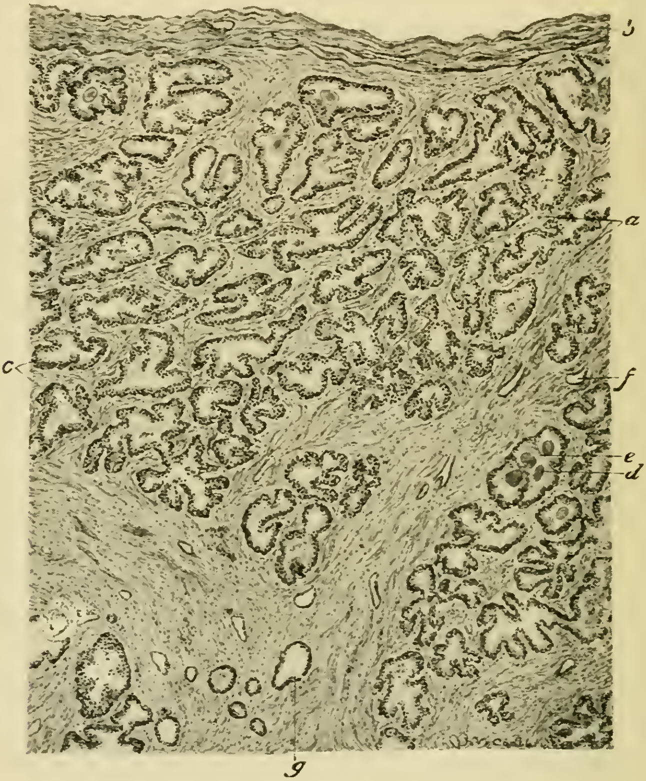


Fig. 211.—Section of the Prostate Gland.
a, Interstitial tissue and muscular trabecula; *b*, capsule; *c*, glands; *d*, amyloid bodies; *e*, secretion; *f*, blood-vessel; *g*, duct.

The **glands** are distributed chiefly lateral and dorsal to the urethra in the form of a short deep crescent, on cross-section. The open dorsal portion is filled in with smooth muscle tissue. Each gland is a branched tubular or tubuloalveolar structure and consists of the secreting tubules and a short duct.

The *secreting tubules* are lined with a *single layer of columnar elements*, although some state that in places several layers may be present. The finely granular cytoplasm contains some yellowish granules. The deeply staining nucleus is basally placed. These cells rest upon a *basement membrane* and outside of this is the areolar *tunica propria* which is composed of white fibrous tissue. The tubules usually have a large diameter and the lumen is large. The *mucosa* is thrown into folds that may be extensive and high, in places extending all of the way across the lumen and dividing the tubule into two areas. The size of the tubules and the number of folds vary in different animals. In the lumina of many of the tubules peculiar masses, circular in outline are seen. These are the *amyloid bodies*, or *prostatic concretions;* they vary in size from a few microns to a millimeter in diameter. These are fewer and smaller in the young and increase in number and size as age advances. The

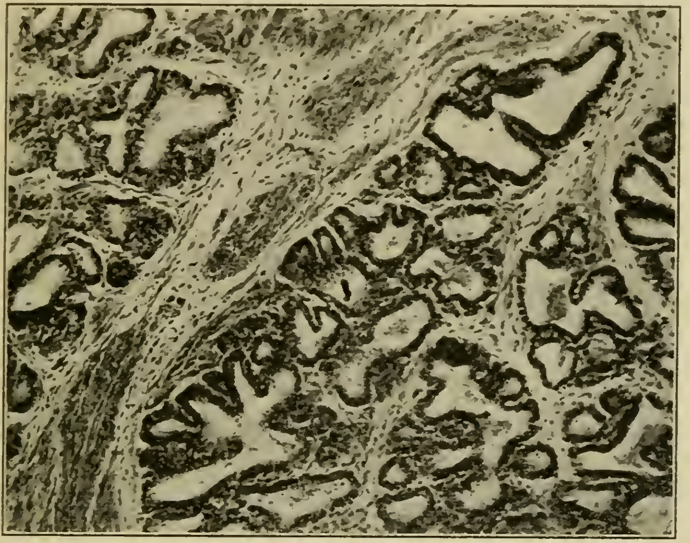


FIG. 212.—SECTION OF THE HUMAN PROSTATE GLAND. (Photograph. Obj. 16 mm., oc. 7.5 X.)

ducts are twelve to fifteen in number on each side. These are comparatively short and each opens individually in the urethra in a groove at each side of the urethral crest called a *prostatic sinus*. These have been described in the male urethra. The proximal ends of the ducts are lined with simple columnar cells but the distal extremities are lined with transitional cells continued in from the prostatic portion of the urethra.

The secretion of the prostate gland is a viscid, opalescent fluid that is acid in reaction. In man the spermia, before they reach the urethra, are amotile or only feebly so but when mixed with the prostatic fluid they become actively motile. In some animals as the white rat and guinea-pig the prostatic fluid is passed into the vagina of the female after the semen has been passed and then it coagulates and forms a plug that prevents the escape of the semen. Atrophy of the prostate occurs after the removal of the testes and in old individuals the organ is subject to hypertrophy.

The *arteries* enter the organ through the capsule and branches follow the trabeculæ and enter the lobules and form extensive capillary plexuses around the tubules and in the trabeculæ for the supply of the abundant muscle tissue. The blood is collected by *venous channels* that run toward the periphery and form a network in the capsule.

The *lymphatics* originate in the septa and follow the venous channels.

The *nerves* are mainly *sympathetic*. They enter the capsule and here numerous small ganglia may be seen. Some of the nerve supply the muscle tissue and other sympathetic fibers apparently end between the epithelial cells. The myelinated fibers terminate in corpuscles that resemble those of Krause.

The **glands of Cowper,** or **bulbourethral glands** are *racemose* glands that empty into the penile portion of the urethra. They are surrounded by a *capsule* of white fibrous tissue that divides the gland into lobes and lobules. The interlobular septa contain both smooth and voluntary straited muscle fibers. The *alveoli* that make up a lobule are lined by *low columnar mucous* cells. Some of these cells, however, contain fine granules that are acidophilic in reaction and do not respond to the mucin stains. These rest upon a cellular basement membrane and tunica propria. The smaller ducts are lined by *cuboidal* cells, while the larger *possess stratified columnar* cells. The **muscle coat** of the main duct consists of longitudinally arranged smooth muscle.

The main duct of each gland passes through the superficial layer of the triangular ligament and empties into the bulbous portion of the urethra.

THE PENIS

The **penis** is an organ surrounded by a loosely attached skin. The latter contains *no adipose tissue.* The thin skin extends over the end of the organ as the **prepuce,** which is covered, upon both surfaces, by stratified squamous cells. The inner surface possesses the characteristics of a mucous membrane.

The organ consists of two main portions, the **glans** and the **body.**

The **glans** is covered by *stratified squamous* cells, and is separated from the body by a narrow constricted area, the **cervix.** At this point, the squamous cells of prepuce and glans are continuous.

The **body** consists of *two* **corpora cavernosa** and the *single* **corpus spongiosum.**

The **corpora cavernosa** lie side by side, forming the dorsal portion of the penis, and are bound together by a thick sheath of white fibrous tissue called the *tunica albuginea.* From the inner surface of this, *trabeculæ* pass inward and form a series of communicating spaces, or caverns. These are venous blood spaces. The trabeculæ contain tortuous arteries, the *helicine arteries*, which, when engorged, become straightened as the organ increases in size. The spaces become filled with blood, and, with the vascular trabeculæ, constitute *true erectile tissue.* This engorgement produces the erection. False erectile tissue depends for its action upon *smooth muscle tissue.*

The **corpus spongiosum** has a thin tunic, and consists of two portions, *urethral* and *peripheral.* The *urethral* part is quite dense and rich in veins, while the *peripheral* part resembles, somewhat, the cavernous portion.

The **glans** is a continuation of the corpus spongiosum, and consists of a delicate network of connective tissue enclosing a number of small spaces. It is covered by a delicate skin, which is continuous with the *prepuce*, or *foreskin*. In the cervix are located a number of glands that secrete the *smegma*. These are the *glandulæ oderiferæ*.

The *blood-vessels* and spaces are numerous. The arterial branches follow the septa, in which they run such a convoluted course as to receive the name of *helicine arteries*. They form capillary plexuses in the trabeculæ, some of which empty into the spaces, while others pass over into the veins. The branches within the tunica form capillaries that empty into the spaces. Anastomoses between arterial and venous capillaries are numerous.

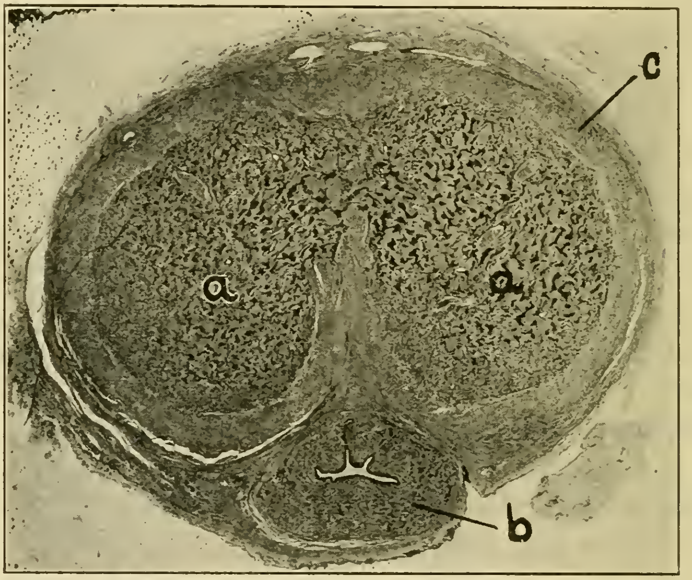


FIG. 213.—CROSS-SECTION OF THE PENIS OF AN ADULT.
a,*a*, Corpora cavernosa; *b*, corpus spongiosum with the urethra; *c*, tunica albuginea. (Photograph. Obj. 72 mm.)

The *emissary veins* receive blood from the tunica and superficial vessels, and partly from the deeper tissues and vessels; they pass through the tunica to empty into the dorsal vein of the penis that lies in a groove between the corpora cavernosa. These veins are pressed upon when the superficial vessels are filled with blood, in that way preventing egress, but not ingress, of the blood.

The *lymphatics* of the penis are abundant. Plexuses exist in the subcutaneous tissue of the body and glans, in the prepuce and in the mucosa of the urethra. The efferents conduct the lymph to the superficial inguinal nodes. The deeper lymph vessels of the skin and of the trabeculæ form a plexus and the efferents conduct the lymph along the blood-vessels to the iliac nodes.

The *nerves* are both *cerebrospinal* and *sympathetic.* The cerebrospinal are both *motor* and *sensor;* the *motor* supply the ischiocavernosus muscles and the *sensor* terminate in various ways. The *free endings* are among the epithelial cells of the glans and urethral mucosa. In the papillæ of the skin are *tactile corpuscles* (Meissner's); deeper in the derma are *corpuscles of Krause* and in the skin of the glands are the *genital corpuscles;* in the connective tissue of the corpora cavernosa *Pacinian bodies* are seen. The sympathetic fibers supply the musculature of the vessels and also the smooth muscle in the trabeculæ. *Vasodilatator nerves* to the vessels are derived from the third and fourth sacral nerves (through the sympathetics) and these are the *nervi erigentes.*

The **paradidymis,** or **organ of Giraldes,** is found in the epididymis. It consists of a number of tubules, in which the lining cells are low columnar or even ciliated. The tubules are closed, and are separated from one another by vascular connective tissue.

The cells that line the various portions of the male genital tract are as follows:

Testicle.		
Seminiferous Tubule	Spermiogonia Sustentacular	Basal layer.
	Spermiocytes, or mother cells.	Second layer.
	Daughter cells,	Third layer.
	Spermids,	Fourth layer.
Tubuli Recti	Cuboidal or squamous.	
Rete Testis	Cuboidal or squamous.	
Vasa Efferentia	Columnar or ciliated.	
Epididymis	Stratified ciliated.	
Vas Deferens	Stratified columnar. Stratified ciliated (some).	
Seminal Vesicles	Simple or pseudostratified columnar.	
Ejaculatory Duct	Simple columnar.	

CHAPTER XIV

THE FEMALE GENITAL SYSTEM

This system consists of the **ovaries, oviducts, uterus, vagina, glands of Bartholin** and **genitalia.**

The **ovary,** the distinctive female organ, is attached to the dorsal surface of the broad ligament and lies in the *fossa ovarica* at the side of the pelvic cavity. It is 3.75 cm. long, 18 mm. wide and 8 mm. thick. It is surrounded by a capsule of white fibrous connective tissue called the **tunica albuginea.** This is not so prominent as that of the testicle. The free surface of the capsule is covered by low columnar cells called the **geminal epithelium.**

The organ consists of **cortex** and **medulla.**

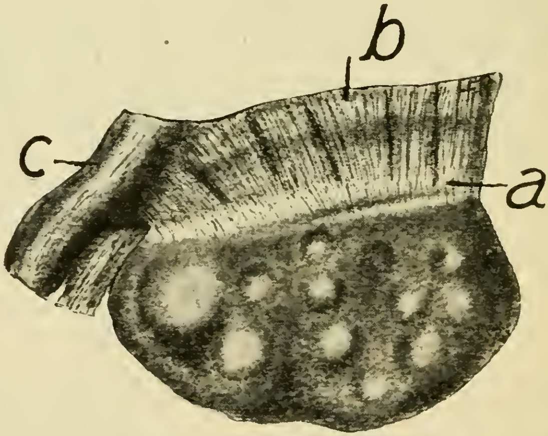


Fig. 214.—A Human Ovary.
a, White line; *b*, mesovarium; C, oviduct. (*After Nagel.*)

The **cortex** is the outer part, and surrounds the medulla, except at one point, at which the vessels enter and leave; this is the **hilum,** and here the medulla comes to the surface. The cortex is the glandular portion, where the cellular elements of the secretion, the **ova,** are formed. It consists of a delicate reticulum, the **stroma,** in which the **Graafian follicles, corpora lutea** in various stages, and occasionally groups of large, polygonal epithelial cells, called the **interstitial cells** are found. The free surface of the stroma is covered by the modified *mesothelial* cells, the **germinal epithelium,** from which the ova are derived. These cells are low columnar elements and not peritoneal endothelial cells.

The **Graafian follicles** are characteristic structures. They vary in size; the smallest are just beneath the tunica albuginea, the medium-sized near the medulla, and the largest extend from the medulla to the capsule, and cause a projection upon the surface of the organ.

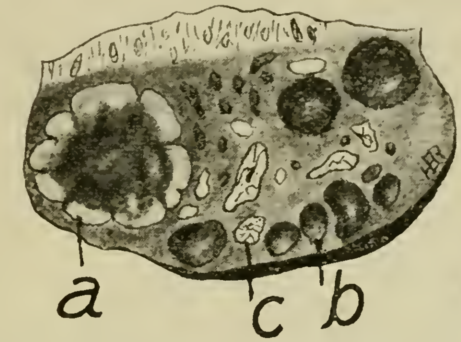


FIG. 215.—A SECTION OF A HUMAN OVARY.
a, Corpus luteum; *b*, Graafian follicles; *c*, corpus albicans. (*After Nagel*)

Externally the mature **follicle** is covered by a layer of condensed stroma called the **theca folliculi;** the *outer* portion of this is called the **tunica fibrosa,** and the *inner* the **tunica vasculosa.** The **theca** is lined by a number of layers of granular cells termed the **zona granulosa,** within which is a space, the **antrum,** filled by a liquid, the **liquor folliculi.** At one point, the granule layer projects into the antrum, and this mass contains the ovum. This projection is called the **discus proligerus,** or **cumulus ovigerus.** Just within the granule cells of the discus is seen a layer of long columnar cells, the **corona radiata.** A well-defined corona radiata indicates that the maturity of the ovum is almost completed (Bischoff, Waldeyer). These cells rest upon a thick homogenous membrane called the **zona pellucida,** which is separated from the ovum by a small space, called the **perivitelline space.** This space is disputed by some writers.

The corona is supposed to give rise to the zona pellucida. The ovum that lies just within the space consists of a cell-wall, the **vitelline membrane,** and cell-body, the **vitellus.** In the vitellus is seen the nucleus, or **germinal vesicle,** which contains the prominent nucleolus, or **germinal spot.**

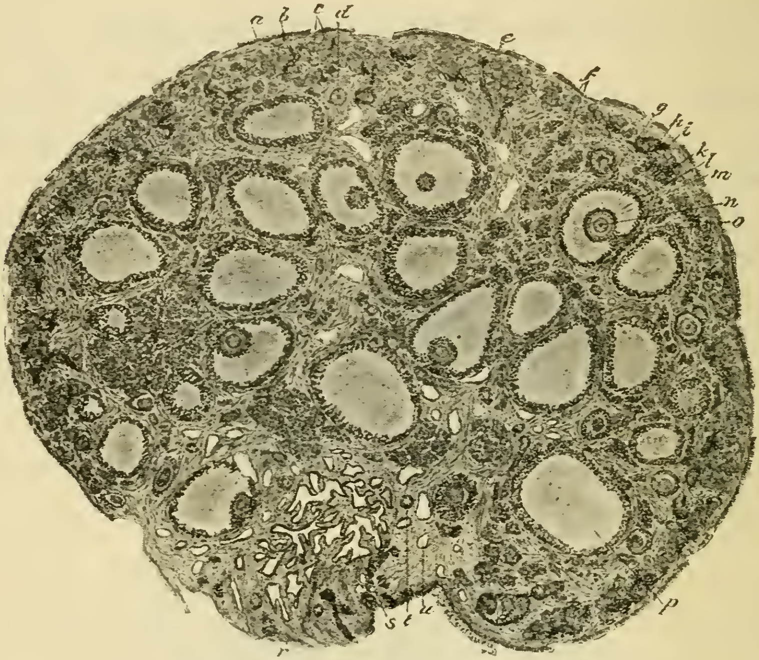


Fig. 216.—Cross-section of Ovary of a Cat.

The Graafian follicles are so numerous that but little of the medulla is seen. *a*. Germinal epithelium; *b*, tunica albuginea; *c*, immature Graafian follicle; *d*, ovum; *e*, cortical stroma; *f*, interstitial cells; *g*, theca folliculi; *h*, zona granulosa; *i*, antrum containing liquor folliculi; *k*, discus proligerus; *l*, corona radiata; *m*, zona pellucida; *n*, vitellus; *o*, germinal vesicle; *p*, follicle without ovum; *r*, hilum; *s*, medulla showing the tubules of the parovarium; *t*, arteriole; *u*, venule.

The **ovum** is the most characteristic and largest cell in the female. Its diameter varies from 0.22 to 0.32 mm. The zona pellucida that surrounds it is quite thick, measuring from 10 to 11 microns (Ebner). It is probably the result of the activity of the cells of the follicle. It is said to contain small radial canals called *micropyles*, through which the *spermium* gains entrance to the ovum in fertilization (denied by Keibel and others). The cytoplasm consists of a delicate reticulum and of yolk granules, the **nutritive yolk,** or **deutoplasm,** and the **formative yolk,** and is transparent in all stages. The *oöplasm* consists of two layers, an outer marginal zone that is finely granular and contains the germinal vesicle, the central portion contains the bulk of the deutoplasm. The latter consists of fine and coarse granules 1 to 3 microns in diameter; they are fatty in nature. The cytoplasm often contains *chromidia* that represent the yolk nucleus; the *accessory nuclei* may be independent or attached to the nucleus and may be also basophilic or acidophilic in reaction. These are said to be remnants of mitotic spindles. *Mitochondria* are also present. The nucleus averages about 30 to 50 microns, is eccentrically placed and sharply outlined by a membrane that possesses

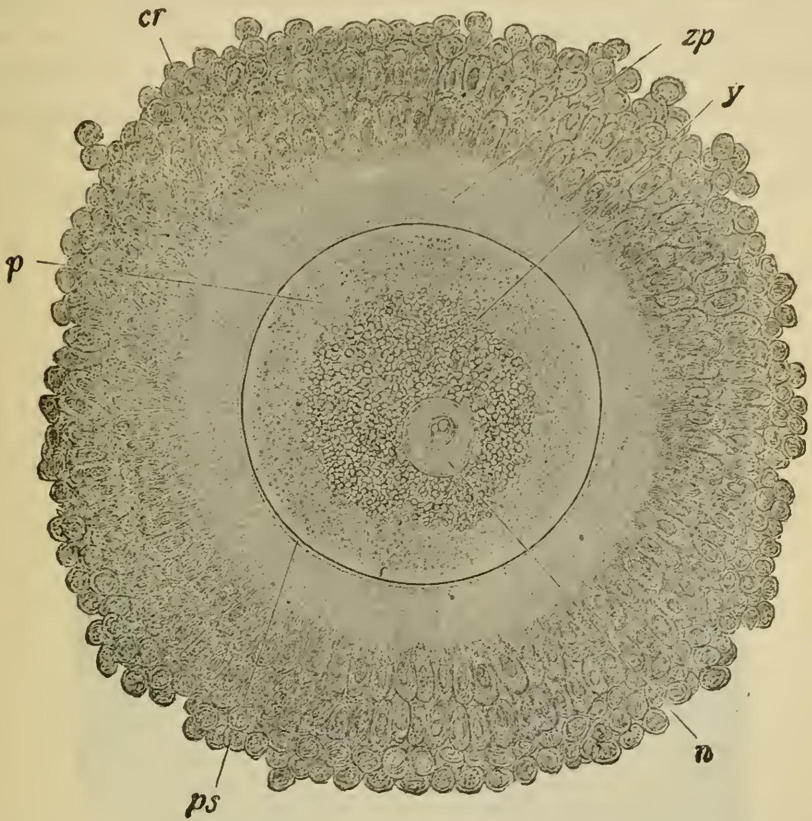


FIG. 217 —OVUM OF A WOMAN THIRTY YEARS OF AGE. (*McMurrich.*)

cr, Corona radiata; *zp*, zona pellucida; *p*, protoplasmic zone of ovum; *ps*, perivitelline space; *y*, yolk (deutoplasm); *n*, nucleus (germinal vesicle) showing germinal spot.

a double contour. The chromatin is rather scant in the matured ovum, but the nucleolus is quite large (7 to 10 microns) and prominent. In the immature ovum the chromatin usually forms a dense mass. The nucleolus may be acidophilic, basophilic or neutrophilic. *The centrosome may be seen in ova that have not undergone maturation. If this process has been completed the centrosome disappears.* Hertwig states that they are found in ova of rabbits up to six or seven weeks of age, and in young guinea-pigs. Multinuclear ova are formed by fusion of separate ova or by direct division of the nucleus alone.

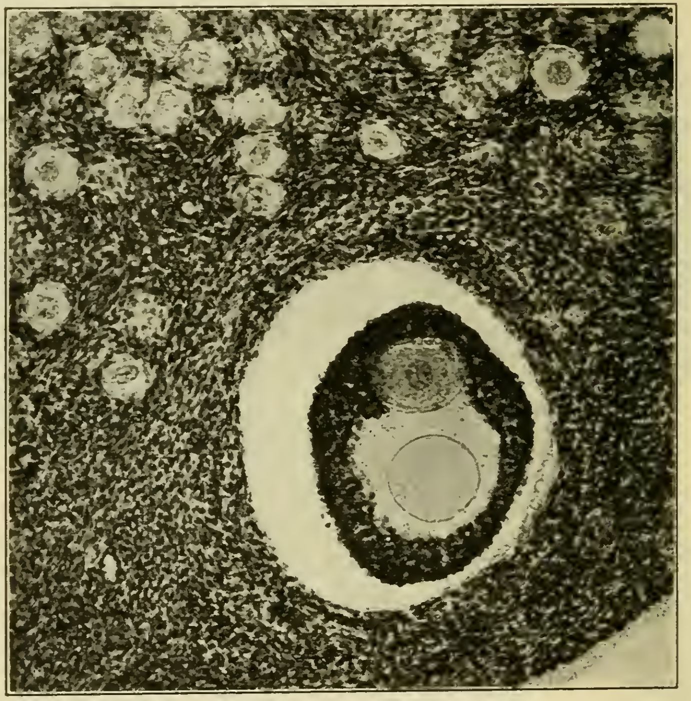


Fig. 218.—Section of the Ovary of a Child at Birth showing Numerous Immature Graafian Follicles and one Well Developed. In the Latter the Zona Granulosa has shrunken away from the Folliculi. (Photograph. Obj. 16 mm., oc. 10 ×).

The Graafian follicles, of which there are about 36,000 in each ovary, are developed during intrauterine life, and all are usually present at birth. At birth or shortly after all oögonia have become mother cells (oöcytes of the first order). Not all of these develop, by any means. Hensen estimates that about 200 follicles in each ovary mature. The other follicles enlarge to a certain stage and then undergo atrophy and are absorbed. The smallest consist of the ovum, surrounded closely by a few layers of small granule cells and a delicate theca. They lie just beneath the tunica albuginea, and show no antrum. The medium-sized follicles lie near the medulla, and present an antrum. The granule cells are more numerous, the ovum larger and the corona radiata and zona pellucida appear. The fully developed follicles extend from the medulla through the cortex beyond the original surface level, projecting varying distances.

The follicular cells are derived from the germinal epithelium, and grow into the stroma in long columns during the developmental period, as the **egg-tubes of Pflueger.** In such a column will be found several large, and a great number of small cells. These columns become separated into a number of groups of cells consisting of one or more large, and many small cells. The large are the **oögenetic,** and the small the **granule** cells. Gradually, the large cells fuse to form a single mass of protoplasm, and all the nuclei, except one, disintegrate. The single cell resulting is called the **oöcyte.** The egg-tubes are separated into these groups by the stroma that grows

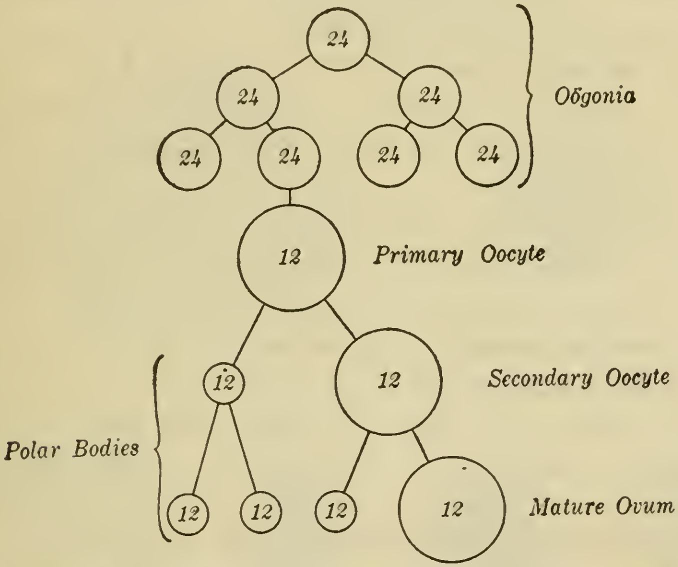


Fig. 219.—Diagram of the Cell Divisions in Oögenesis. (Compare with Fig. 209.) (*Lewis and Stöhr.*)

into the columns. This stroma further condenses around each group to form the **primitive theca.** Toward the age of puberty, these follicles begin to develop, though they may start sooner. The granule cells increase rapidly in number, and some of the more central ones disappear by disintegration or liquefaction. This gives rise to the space, or **antrum,** which becomes filled by a liquid, the **liquor folliculi.** The latter is probably derived from the blood.

Follicles containing several ova are formed as follows: (1) The egg-tube becomes separated, incompletely enclosing several germ cells in one mass; (2) fusion of two originally separated follicles.

Maturation is the process by which the **polar bodies** are formed and extruded. During intrauterine life oögonia multiply rapidly as do the spermatogonia in the male, but the latter process does not occur until the male is twelve to fifteen years of age. The resulting oögonia are small and undergo a period of rest and then growth and are then called primary oöcytes. These undergo the maturation process which is the same as in the spermiogonia. The germinal vesicle migrates toward the periphery, and undergoes mitotic change. Only *twelve chromosomes,* the *haploid number,* are formed due to fusion by pairs; these divide longitudinally forming twenty-four. When the **nuclear spindle** is formed parallel to one of the radii, the **peripheral half,** surrounded by a small amount of cytoplasm, is thrust out of the cell. This is the **first polar body.** *Without rest,* the remaining chromosomes immediately undergo division again, and the extrusion process is repeated. This is the **second polar body.** The remaining chromosomes form a new nucleus called the **germ-nucleus.** By this change, the number of chromosomes is *reduced from twenty-four, in the oögonium, to twelve, in the matured ovum.* The first polar body often divides into two, and, as a result of maturation, four cells are formed. Of these four, the ovum is the only one capable of producing an offspring. The three polar bodies disintegrate and disappear. This is entirely different from the change in the testicle. In that organ, the **spermiocyte** gives rise to **four cells,** each of which becomes a **spermium,** *capable of fertilization.*

Maturation of the ovum differs from karyokinesis in the following ways: (1) The nucleus moves to the periphery of the cell instead of remaining in the middle; (2) only one-half the somatic number of chromosomes is formed; (3) the resulting daughter cells contain only one-half the somatic number of chromosomes; (4) the resulting cells are unequal in size; (5) the successive divisions occur without rest; (6) the mature ovum contains no centrosome; (7) only one cell is of functional importance.

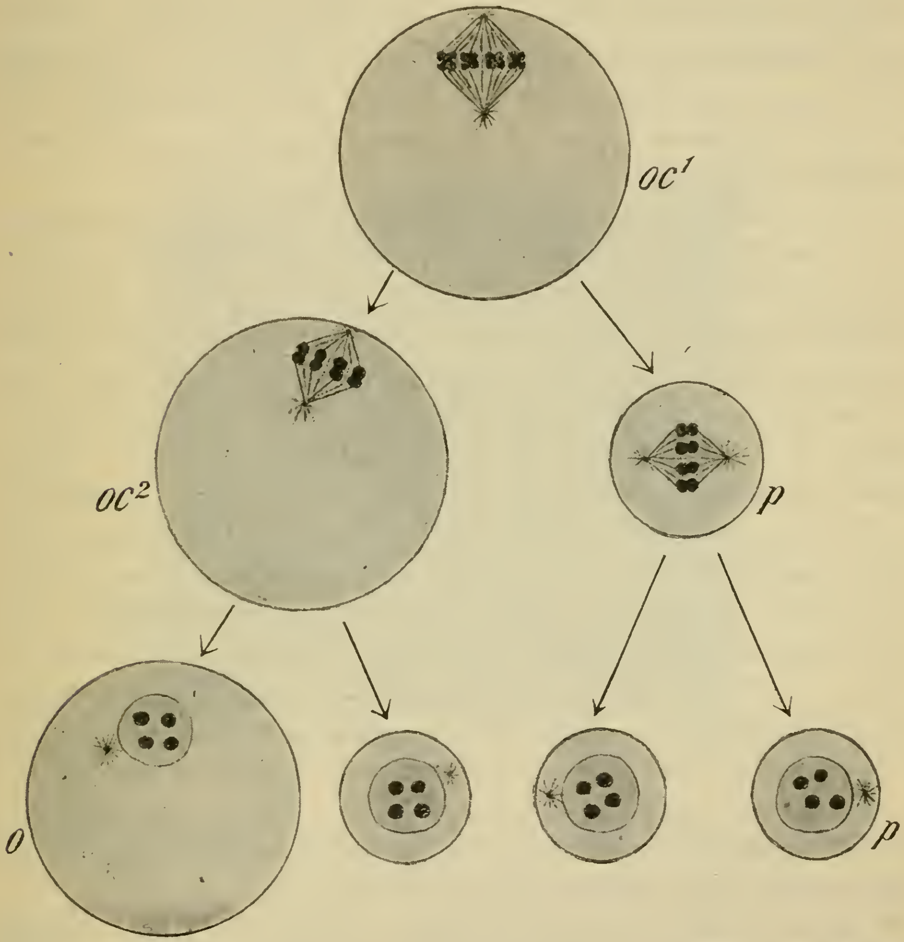


FIG. 220.—DIAGRAM ILLUSTRATING THE REDUCTION OF THE CHROMOSOMES DURING THE MATURATION OF THE OVUM. (*McMurrich.*)

Ovum; *oc*¹, oöcyte of the first generation; *oc*², oocyte of the second generation; *p*, polar globule.

The differences between maturation of the ovum and maturation of the spermiocyte are as follows: The primary oöcyte forms four granddaughter cells of which only one is nearly as large as the primary cells and the other three are very small immature cells. Although all contain the same number of chromosomes, twelve, only the matured ovum is of functional importance; the other three small cells, or *polar bodies* disintegrate and disappear. As the spermiocyte undergoes maturation (*spermiogenesis*) four granddaughter cells are formed but these are all small and of the same size. *Two* contain only *eleven chromosomes* and *two* contain *twelve chromosomes.* All of these cells, however, are of functional importance as any one is capable of fertilizing a matured ovum.

As the follicle increases in size, it approaches the tunica albuginea, and causes it to protrude. The stroma intervening between the ovum and the tunica gradually diminishes until merely the tunica albuginea remains. As the follicle increases and the pressure within becomes greater, the tunica becomes progressively thinner, until it is no longer able to withstand the pressure. A small area, the *stigma,* is the thinnest part and indicates the place of rupture. Then it ruptures, and the *liquor folliculi* and the *ovum, surrounded by the granule cells,* are cast out of the ovary. The vessels of the tunica vasculosa rupture, and the follicle fills with blood. When this occurs, the body is called the **corpus hemorrhagicum.** The cells of the theca penetrate the clot, and cause this to organize. In addition to these cells, there are certain other large cells that possess a yellowish pigment. These are the **lutein cells,** and their function is unknown. These are derived from the theca. These increase in number and make a very large body. The corpus exhibits a pleated appearance due to the invagination of the white fibrous tissue of the theca folliculi and the blood-vessels.

If the ovum has not been fertilized, this body is called a **corpus luteum spurium,** which rapidly undergoes atrophy. In a few weeks, it leaves a white scar called the **corpus albicans,** due to the increase of radially disposed white fibrous tissue and its resultant contraction. If fertilization has occurred, then the body persists until near the end of pregnancy, and is termed the **corpus luteum verum.**

The **corpus luteum** seems to be a gland of short duration. It seems to secrete a substance that causes the *second succeeding menstrual flow,* that is, of the next month. Experimental study upon animals, in which the follicles were destroyed, showed an almost invariable absence of the second succeeding period. The preceding flow was caused by the follicle preceding the experiment. This secretion also stimulates the uterus, and aids the implantation of the ovum in the uterine mucosa, providing fertilization has occurred (Frankel). During pregnancy it seems to prevent the maturation of Graafian follicles, while during the later stages of pregnancy it is said to exert an influence upon the mammary gland.

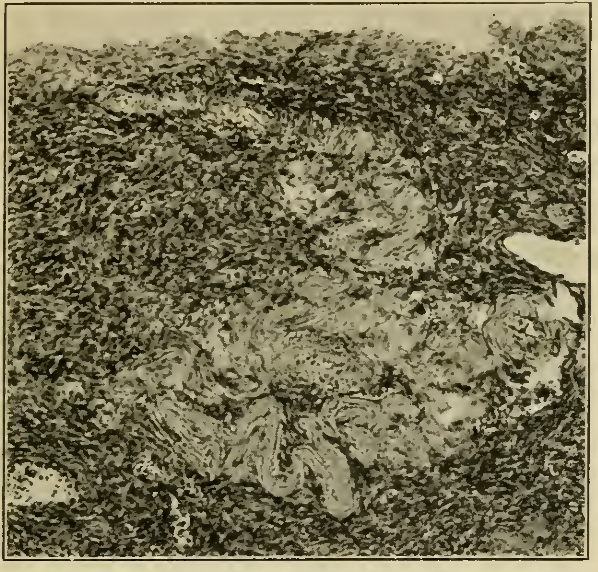


Fig. 221.—Section of a Corpus Albicans in the Cortex of the Ovary of an Adult Female. (Photograph Obj. 16 mm., oc. 7.5 ×.)

Of all the follicles formed, but few are ever fertilized. A great number atrophy; in the remainder, maturation occurs. Of these ova; there are those which are cast into the abdominal cavity and absorbed by the peritoneum; those which pass down the genital tract and are cast out, or disintegrate, and lastly, those that become fertilized.

Ovulation includes the delivery of the ovum from the follicle and its passage through the genital apparatus. In the lower animals, in which the young are developed from eggs outside of the body (**oviparous**), this process is evinced by the "*laying of the egg.*" In the **viviparous animals,** or those in which the offspring is developed within the mother, this process is not accompanied by any outward signs or manifestations. In the temperate climate, it begins at about the twelfth to the fifteenth year, and continues until about the forty-fifth to the fiftieth year. At this time ovulation ceases, and fertilization cannot occur thereafter.

The **medulla** consists of a loose network formed by large, coarse bundles of white fibrous tissue, in which strands of **smooth muscle tissue** are found. These latter are limited to the medulla. In the meshes of the stroma are seen the **interstitial cells,** which are more numerous than in the cortex. The *interstitial cells* resemble those of the testis. Some believe them to be the remains of some of the cells of the fetal genital organs, others that they are scattered germinal epithelial cells that are considered capable of developing into ova; still others consider them derivatives of the connective-tissue cells and not embryonal remains. In this part of the ovary are found the large blood-vessel trunks which are very numerous.

The *ovarian* and *uterine arteries* supply the ovary. These vessels pass into the hilus of the ovary between the layers of the mesovarium forming a number of branches that enter the medulla. These branches are comparatively large and have a spiral course resembling the helicine arteries of the male. Their walls are unusually thick, due to the presence of an excessive amount of smooth muscles a great deal of which is longitudinally arranged. Branches from these pass into the cortex where capillary plexuses are formed in and around the theca of the Graafian follicles and others form capillary plexuses in the stroma. The extent of the plexuses around the follicles depends upon the state of the follicle. When these are young and immature the plexus is not extensive; as the follicles mature the plexus becomes greater and increases until after the rupture of the follicle and during the active stage of the corpus luteum. As this retrogrades the capillary plexus becomes reduced so that in the corpus albicans it is less than in the surrounding stroma. The blood is collected by *venules* that have thin walls; these pass to the medulla where they form the *pampiniform plexus of veins* analogous to that of the male. From this plexus the *ovarian vein* carries the blood from the organ.

Lymph spaces are numerous and they pass the lymph into large capillaries that accompany the blood-vessels. These capillaries form plexuses around the large follicles and the lymph is conducted by efferents to the hilus where these vessels join those from the body of the uterus. The lymph ultimately reaches the pelvic and lumbar nodes.

The *nerves* are derived from the *ovarian plexus of the sympathetic system*, enter the hilus and are distributed to the smooth muscle in the stroma, the smooth muscle of the vessels and some fine fibrils are said to end between the epithelial cells of the zona granulosa. *Pacinian bodies* are also described as being present. Winniwarter states that along the nerves and in the medulla there are small ganglia that contain, besides the ganglion cells, groups of *pheochrome cells.*

The **parovarium,** or **epoöphoron,** lies near the hilus of the ovary, and consists of a number of short vertical tubules united to a single horizontal tube. The vertical tubules are short, and are lined by low columnar cells. The horizontal tubule has a larger diameter than the preceding, and is lined by the same variety of cells. It often lies deep in the broad ligament.

The **paroöphoron** lies in the broad ligament, between the ovary and uterus, and consists of a number of short, closed tubules lined by low columnar cells. The tubes resemble the vertical tubes of the epoöphoron.

THE OVIDUCT

Although the ovary possesses no excretory apparatus like other glands, the **oviduct,** or **Fallopian tube,** acts as such.

The **oviduct** consists of the outer **fimbriated end,** the middle, or **ampulla,** and the inner **uterine end,** or **isthmus.** It has three coats, **mucous, muscular** and **fibrous.**

The **mucous** coat consists of *simple ciliated* cells that lie upon a *basement membrane* and *tunica propria. A muscularis mucosæ is absent.* The cilia wave in such a manner as to create a current toward the uterus. Here and there are seen patches of nonciliated cells but none of the glandular nature are present. The *basement membrane* is thin and homogeneous. The *fimbria* are finger-like, or fringe-like projection one of which is especially large and is attached to the ovary. The others are free. Each fimbrium consists of a core of fibro-elastic tunica propria covered, on the lumen side by simple ciliated cells and upon the abdominal cavity side by the endothelial cell of the peritoneum, though at times the ciliated cells seem to surround the whole structure. The *tunica propria* is thrown into longitudinal folds that are high in the fimbriated end, but diminish in height as the uterus is approached. These folds are the **villi,** which possess a very narrow base, but the part lying in the lumen of the tube is greatly branched forming the secondary folds. The tunica propria consists of white fibrous and yellow elastic tissues, in which diffuse lymphoid tissue is found. The mucosa is thickest at the fimbriated extremity and the lumen varies from 2 to 8 mm. in diameter in the different parts. The uterine extremity has the smallest lumen.

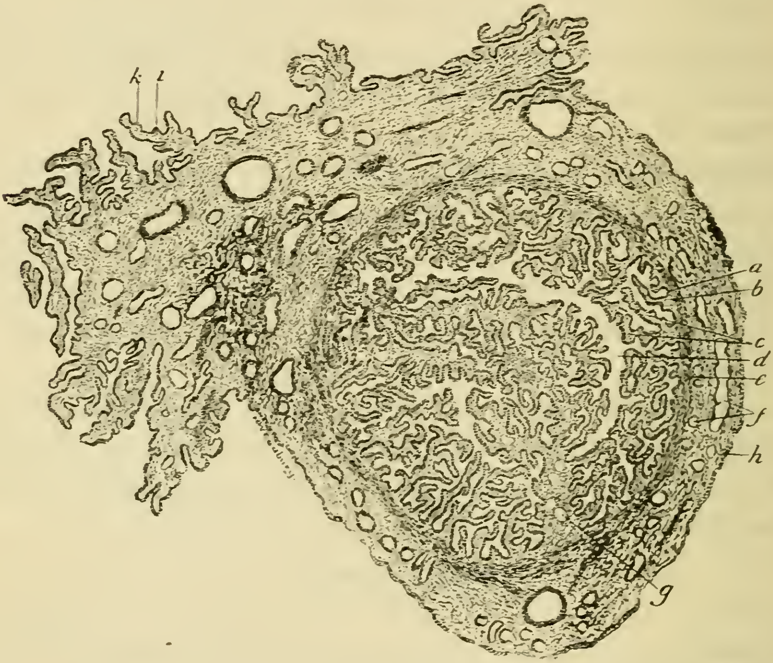


Fig. 222.—Cross-section of the Human Oviduct.

a, Epithelium; *b*, tunica propria; *c*, villi; *d*, muscular coat, inner circular layer; *e*, muscular coat, outer longitudinal layer; *f*, blood-vessels in the fibrous coat; *g*, blood-vessels in villus; *h*, fibrous coat; *k*, epithelium of fimbria; *l*, tunica propria of fimbria.

The **muscle coat** consists of smooth muscle tissue. This is arranged into *inner circular* and *outer longitudinal layers.* The *inner circular layer* is the broader and some of its fibers are oblique in direction and may penetrate the tunica propria of the mucosa. This layer is thickest at the uterine extremity of the oviduct. The *outer longitudinal layer* is in general poorly developed and in areas may be wanting. It is said to be best developed opposite to the attachment of the mesosalpinx. It is thickest at the fimbriated extremity of the oviduct. At the uterine extremity an *inner longitudinal layer* is added. This probably represents a muscularis mucosæ. The whole muscle coat is thickest at the uterine end of the tube.

The **fibroserous coat** consists of a thin layer of white fibrous tissue that is the real fibrous coat. This is invested by a layer of the peritoneum which is derived from that of the broad ligament. Opposite to the free edge of the tube the two layers of the peritoneum unite and form a delicate band that connects the tube to the broad ligament; this band is the *mesosalpinx.* Through this the vessels, nerves and lymphatics gain access to or leave the organ.

The *arteries* are branches of the ovarian and uterine arteries. These pass to the tube between the layers of the mesosalpinx and at the fibrous coat send branches into the other coats. These form capillaries in the muscle and mucous coats and the blood is collected by *venules* that form a plexus in the muscle coat and from here the blood is carried by larger venules that accompany the arteries.

The *plexus of lymph vessels* in the mucosa sends the lymph to the serous coat, as is also the case of the plexus in the muscle coat. From the serous coat efferents carry the lymph to pelvic and lumbar nodes.

The *nerves* are from the ovarian sympathetic plexus. The branches pass to the muscle tissue of the tube and the vessels and other fibers form a subepithelial plexus from which probably fine branches pass to the epithelial cells of the mucosa.

THE UTERUS

The **uterus** is a flattened, pear-shaped organ that consists of **body** and **cervix.** It is an important organ, as within it develops the offspring, in viviparous animals. It is about 7.5 cm. long, 5 cm. wide and 2.5 cm. thick in the virgin. In this condition it weighs from 1 to 1½ ounces. After the first pregnancy it never returns to this weight and size. All parts consist of **mucous, muscular** and **fibrous** coats.

The **mucous** coat of the body is about 2 mm. in thickness (Hitschmann and Adler) of a grayish color and smooth, and is composed of *simple ciliated cells, basement membrane* and *tunica propria.* Mandle (1908) states that the amount of ciliated epithelium varies. Within the tunica propria are found a rich capillary plexus and diffuse lymphoid tissue. The surface is not smooth, but is broken by the formation of **glands**. These are tube-like depressions, lined by the simple ciliated cells, of the *branched tubular variety;* these glands are slightly spiral, in course obliquely directed and usually their ends are bent upon themselves. They are the **uterine glands** and extend to the muscular coat, and may even penetrate the inner layer. They are often so long that, when they reach the muscular coat, they turn and extend parallel to it for some distance.

The *tunica propria* of the uterus is said to resemble embryonic connective tissue. Elastic fibers are said to be absent and the white fibers are present in small numbers. Cells are very numerous, some of which are lymphocytes and these constitute diffuse lymphoid tissue. The other cells are oval, or spindle-shaped and may have branches. In addition, especially during the formation of the menstrual mucosa, there are some large clear cells present called *decidual* cells. These are also found in the placenta and are no doubt derived from the uterus during the formation of the placenta.

The **mucosa** of the **cervix** is a little different. The *uterine end* is lined by *simple ciliated cells,* and glands are present. The *vaginal end* is lined by *stratified squamous cells,* and *gland-like depressions are present.* The orifices often closed, causing them to become distended with secretion. In this condition, they produce globular projections called the **ovuli Nabothi.** The cervical mucosa is thrown into folds called the **plicæ palmatæ.** The vaginal portion of the cervix is covered by stratified squamous cells.

The **muscle coat** of the body of the uterus is arranged in layers in some animals but in the human being these layers are not distinct.

In the cervix, however, they are distinct. In the *body* the *innermost layer* represents a greatly *hypertrophied muscularis mucosæ* and according to Shäfer this forms the greater part of the thickness of the wall of the uterus. In the *fundus* the bundles of fibers form concentric rings around the openings of the oviducts; in the *cervix* and *lower part of the body* they have a circular direction and a few internal longitudinal fibers may be present. The *middle portion* consists of bundles of fibers that have a *circular direction* but interlace somewhat. The main blood-vessel trunks are in this layer and these with the areolar tissue present make this the widest layer of the organ. The presence of the blood-vessels makes it resemble a submucosa and the layer is called the *stratum vasculare.* There may be some longitudinal fibers along its internal part. According

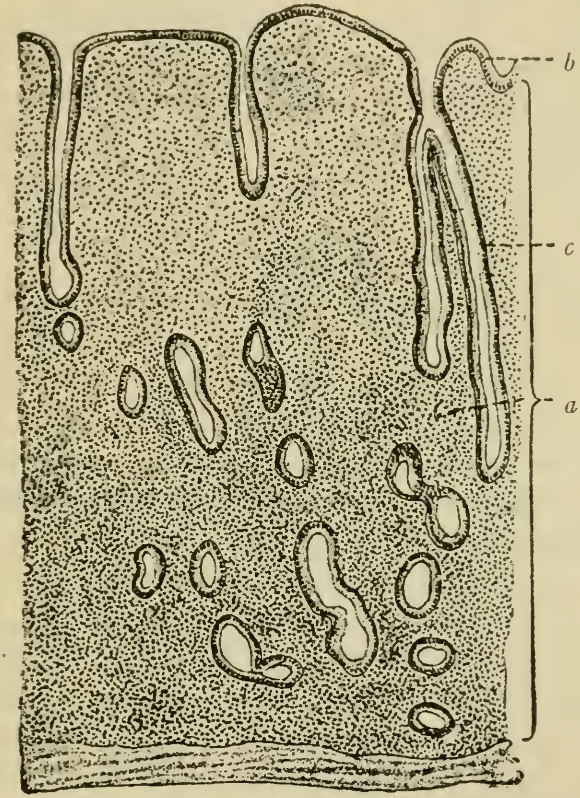


FIG. 223.—RESTING UTERINE MUCOSA.
a, Mucosa; *b*, epithelium; *c*, gland tubule. (*Stöhr's Histology, after Böhm and Davidoff.*)

to Shäfer this layer is best developed over the dorsal and lateral parts of the fundus. The outermost fibers are called the *stratum supravasculare.* The fiber bundles are chiefly longitudinally directed and form a thin layer just beneath the serous coat. Some of the bundles are continuous with those of the oviducts, the round ligaments and broad ligaments. The innermost fibers of this layer have a circular direction.

In the *cervix* the muscle fibers are arranged into distinct layers, *inner* and *outer longitudinal* and *middle circular.* The circular fibers form the *sphincters* at the internal os and external os.

The muscle fibers average 50 to 60 microns in length; but, during pregnancy, they lengthen to from 300 to 600 microns.

The **fibrous,** or **serous,** coat is quite thin. It is completely invested by peritoneum in the **body.**

Menstruation is the periodic change that occurs in the uterine mucosa, every twenty-eight days, during the child-bearing period (thirteenth to fiftieth year). The superficial part of the mucosa softens, disintegrates and is removed. It is divided into stages, the **premenstrual,** or **hypertrophic, menstrual,** or **desquamative, postmenstrual,** or **reparative** and **intermenstrual,** or **resting stages.**

1. The **premenstrual** stage requires usually six to seven days. The mucosa increases two to three times in thickness due to edema and enlargement of cellular elements. The gland lumina become wider and irregular due to the projection of epithelium and tunica propria. The secretion in the glands is mucous. The superficial connective tissue cells become larger, rounded and the cytoplasm becomes clearer; they represent preliminary decidual cells. In these changes the mucosa becomes divided into two layers, stratum compactum and stratum spongiosum. The vessels dilate and become engorged and the mucosa is of a deep red color. Hemorrhages occur within tunica propria, these areas become confluent forming a subepithelial hematoma.

2. The **menstrual** stage shows the epithelial denuded at intervals permitting the blood to flow mixed with edematous fluid and glandular secretion. As a result of this outflow there is a rapid shrinkage in the thickness of the mucosa. The glands are collapsed, the lumina straight and the cells smaller and lower. The decidual cells

degenerate, disappear or diminish in size. The surface epithelium may be only slightly affected or the entire stratum compactum may be expelled. This stage occupies from three to five days during which time 26 to 52 cu. cm. of blood is lost according to Hoppe-Seyler.

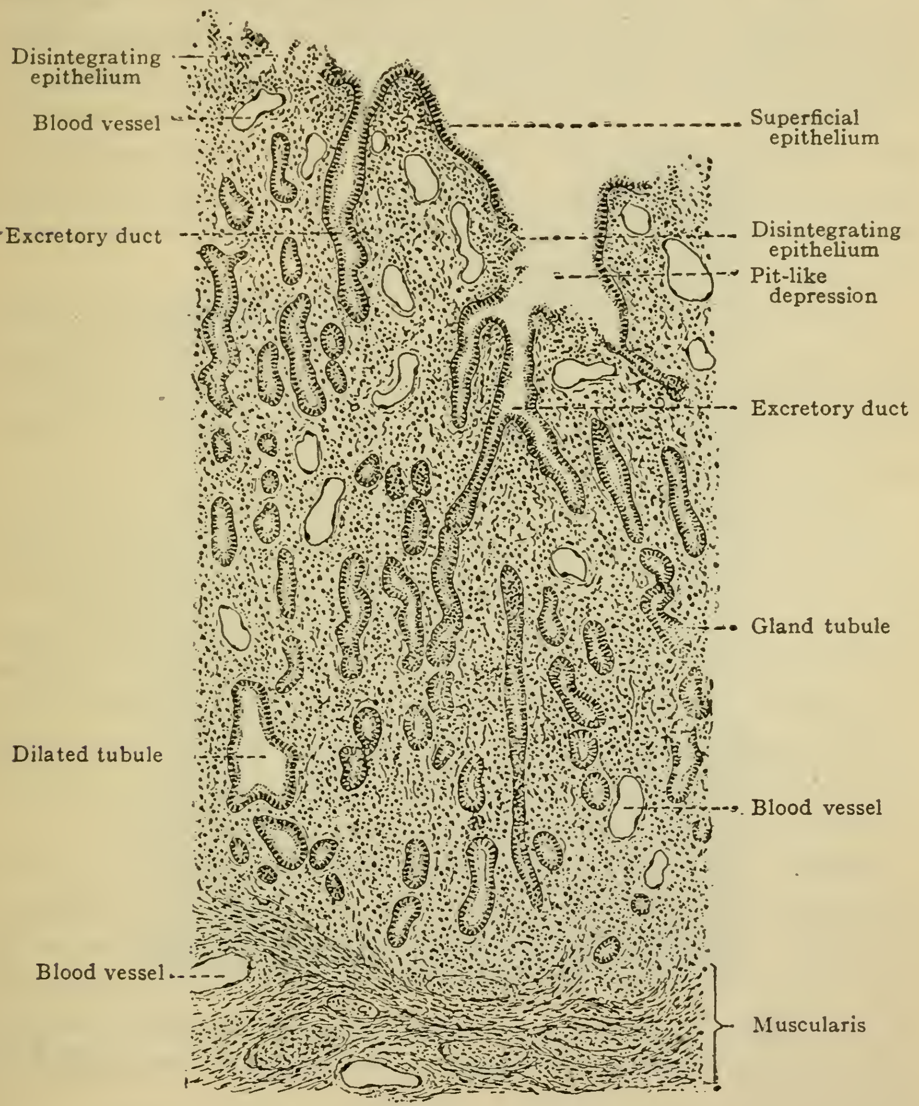

Disintegrating epithelium
Blood vessel
Excretory duct
Dilated tubule
Blood vessel
Superficial epithelium
Disintegrating epithelium
Pit-like depression
Excretory duct
Gland tubule
Blood vessel
Muscularis

FIG. 224.—MUCOUS MEMBRANE OF A VIRGIN UTERUS DURING THE FIRST DAY OF MENSTRUATION. × 30. (*Schaper.*)

3. In the **postmenstrual** stage the glands are narrow and straight, the former decidual cells are long and fusiform and only small

hemorrhagic areas are to be seen. After a few days the glands become wavy, the lining cells enlarge somewhat and the mucosa becomes quiescent. This stage requires from four to six days.

4. During the **intermenstrual** stage the gland cells, at first small and closely set, enlarge and the cytoplasm becomes hemogeneous and acidophilic. In the tunica propria leukocytes and even solitary nodules are seen. The gland cells produce secretory granules that are passed into the gland lumina. This stage occupies fourteen days. Should fertilization occur at this time of the premenstrual stage, the other three stages may not take place. Bryce and Teacher claim that menstruation occurs merely to maintain a mucosa at all times ready for the formation of a decidua.

The uterus of the female at birth is different in appearance than at the age of puberty and in the adult condition. The mucosa is comparatively thin and the epithelial runs a smooth and unbroken course as glands are not present. These form between the first and fifth years.

The *blood-vessels* are important. Two arteries, the uterine and ovarian, supply the organ. The main branches of these arteries pass to the middle circular layer of muscle, where they form an extensive plexus of large vessels as in the submucosæ of other organs. From this plexus branches pass to the muscle coat and form plexuses of capillaries; other branches pass to the mucosa and form a dense capillary meshwork just under the epithelium. The extent of this plexus will differ at the various stages of menstruation. The blood is collected by *venules* that accompany the arterial channels.

Lymphatic spaces and *capillaries* are numerous in the mucosa. The capillaries form an extensive meshwork and receive the lymph from the spaces. The lymph is carried by efferents to the plexus in the inner muscle layer and then to another in the muscular coat proper and from here, by means of valved vessels, the lymph is conducted to the subserous plexus, ultimately to be carried to the neighboring lymph nodes.

The *nerves* are from the *cerebrospinal* and *sympathetic systems* through the pelvic plexus. These supply the muscle tissue of the uterus and of the vessels from a plexus formed in the stratum vasculare; other fibers from this plexus are said to form a delicate subepithelial plexus from which terminal fibers pass between the epithelial cells of the mucosa.

THE VAGINA

The coats of the **vagina** are the same as those of the uterus.

The **mucous** coat consists of *stratified squamous* cells, supported by *basement membrane* and *tunica propria*. The subepithelial portion of the tunica propria is papillated. The deeper portion contains many large elastic fibers and considerable diffuse lymphoid tissue. Occasionally, some simple tubular glands are met with, and the lining cells are of the simple ciliated variety.

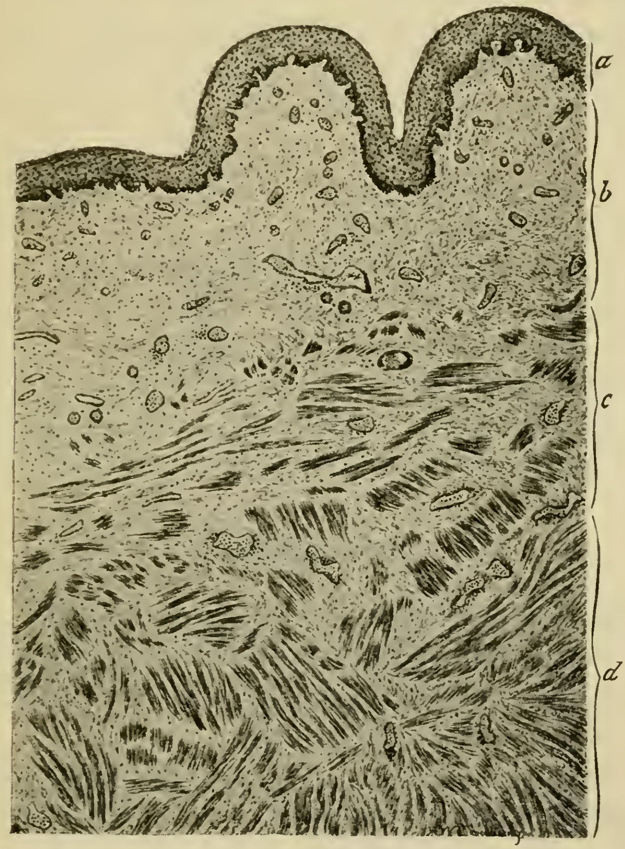


FIG. 225.—CROSS-SECTION OF SEGMENT OF HUMAN VAGINA.
a, Stratified squamous epithelium; *b*, tunica propria; *c*, inner circular muscle fibers; *d*, outer mixed muscle fibers.

The **muscular** coat varies in thickness, that nearer the outlet being the thicker. The layers are not sharply separated from one another, but the general direction is *inner circular* and *outer longitudinal.* The fibers are long and slender. The mucous and muscular coats are thrown into folds that are called **rugæ.** The outlet of the vagina is surrounded by voluntary striated muscle tissue that is called the *sphincter vaginæ* muscle.

The **fibrous** coat consists of dense fibrous tissue, and serves to connect the vagina with the surrounding tissues and organs. It contains the large blood-vessels, lymphatics and nerves.

The larger *vessels* lie in the deeper portion of the fibrous coat and send branches into the mucosa and muscularis. The capillaries of the mucosa pass chiefly to the papillæ. The *veins* form dense plexuses beneath the fibrous coat. Large vessels occur in the deeper part of the mucosa, causing it to resemble *cavernous* tissue.

The *lymphatics* follow the same course as the blood-vessels. The *nerves* are both myelinated and amyelinated. These form an extensive plexus containing a number of small ganglia in the fibrous coat; from this plexus *motor* fibers pass to the muscle tissue of the vessels and vaginal wall and *sensor* fibers pass to the epithelium of the mucosa.

THE GENITALIA

The **vaginal orifice** is guarded by a delicate annular, or crescentic membrane called the **hymen.** This consists of white fibrous tissue covered upon its external and internal surfaces by *stratified squamous* cells. Occasionally, it is very vascular.

Just outside of this fold, the primitive urinogenital sinus spreads to form the **vestibule** of the vagina. This is a triangular space, with the apex formed by the junction of the labia minora, the sides by these folds and the base by the vaginal orifice. It contains the opening of the urethra. This space is lined by *stratified squamous* cells. In the tunica propria, are found a great many elastic fibers and *mucous* and *sebaceous glands,* especially near the opening of the urethra. The lower portion of the tunica propria contains so many large venous channels that it is practically **erectile tissue.**

Opening into the vestibule upon each side is a gland, the analog of the gland of Cowper of the male. This is the **gland of Bartholin,** which is a *compound racemose gland,* and the acini are lined by large, clear, *mucous* cells. The ducts are lined by low columnar cells.

Covering the vaginal orifice, to a greater or less extent, are seen the **labia minora,** or **nymphæ.** These consist of a central mass of loose connective tissue, in which the blood-vessels are abundant, especially the veins. In the tissue between the veins, smooth muscle tissue exists, and this with the vascularity, forms the **erectile tissue.** The folds are covered upon both sides by **stratified** *squamous* cells that rest upon a *papillated tunica propria.* In these papillæ, capillary plexuses are seen. *Sebaceous glands are numerous,* but *hairs* and *sweat-glands are absent.*

The **glans clitoris** lies in the tissue formed by the junction of the labia minora. It is covered by *stratified squamous* cells. The central part consists of **erectile tissue,** and many large and small vascular papillæ are present. *Genital corpuscles* and *sebaceous glands* are found. The **glans** is covered by a fold of skin, the **prepuce,** in which the sebaceous glands are quite numerous.

The **labia majora** are merely folds, or pouches of skin. Their outer surfaces are covered by ordinary skin. In the subcutaneous tissue are seen numerous vessels, nerves, glands, bundles of smooth muscle and an abundance of adipose tissue. Along the median line, they come in contact with each other, and the skin surface is somewhat modified. Here elastic and muscle tissue are abundant, but adipose tissue is wanting. The skin of the labia majora is somewhat darker than that in the immediate neighborhood, due to the presence of pigment in the epithelial layers. Over the pubis, the two labia meet and form a prominent mass, the **mons veneris.**

The various portions of the female genital tract are lined by the following cells:

Oviduct	Simple ciliated.
Uterus.	
Body	Simple ciliated.
Cervix Uterine end	Simple ciliated.
Vaginal end	Stratified squamous.
Vagina	Stratified squamous.
Vestibule	Stratified squamous.
Labia	Stratified squamous.

CHAPTER XV

THE PLACENTA AND UMBILICAL CORD

A description of the formation of the **placenta** and **cord** must be given in order to understand their structure at term.

Should the ovum become fertilized, it is passed down the oviduct by the ciliated cells, as fertilization usually occurs in this portion of the genital system. It is surrounded by the *zona pellucida* and *corona*, or *zona radiata*. The mucous membrane of the uterus becomes thickened, as for menstruation, and the ovum becomes lodged, usually in the fundus. The implantation process requires about one day. If the implantation is in the main cavity of the uterus it is called *central*, as in carnivors, rabbits, etc.; if in a furrow or diverticulum it is called *excentric*, as in hedge-hog and mouse; if it is by destruction or erosion of the mucosa and therefore outside of the uterine cavity proper in the interstitial tissue it is called *interstitial*, as in man and guinea-pig.

The mucosa of the uterus is divided into regions: that immediately beneath the ovum is the **placental decidua**, or **decidua basalis**; the ovum becomes covered by a portion called the **decidua capsularis**, or **ovular decidua**, or **reflex decidua**; the remainder is the **uterine decidua**, or **decidua parietalis**.

The ovum divides and redivides, and passes down the oviduct toward the uterus. By the time the ovum reaches this organ it is 5 mm. in diameter and the *mesoderm* has appeared. These cells form an irregular mass, the **morula** (see Fig. 226, A). The outer cells of this mass arrange themselves beneath the zona pellucida as the **trophoderm**, or **outer cell mass**, while the remainder constitute the **inner cell mass**. The entire structure grows rapidly, and the inner cell mass becomes differentiated into three groups of cells, the *ectodermal* mass, *entodermal* mass and *mesodermal* mass (B, Fig. 226). Cavities appear in these masses through the vacuolization and disappearance of some of the cells. That within the ectodermal mass is the *amniotic*

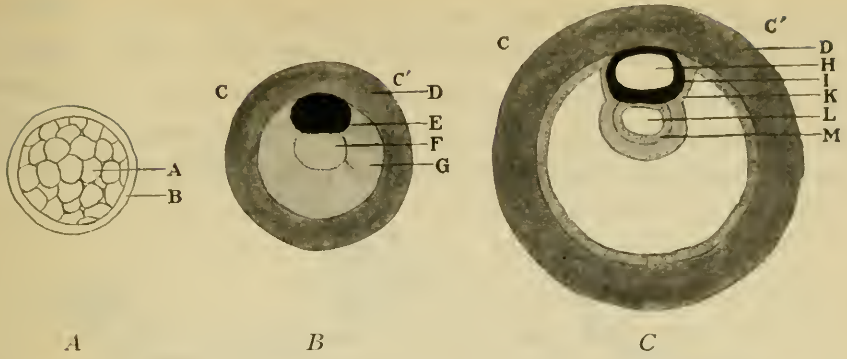


FIG. 226.

A, Morula—a, Morular cells; b, zona pellucida. *B*, Later stage—d, Trophoderm; e, ectodermal mass; f, entodermal mass; g, mesodermal mass. *C*—d, Trophoderm; h, amniotic cavity; i, ectoderm; c, c′ indicate respectively the direction of the cephalic and caudal extremities of the embryonic area. The trophoderm is shaded, the ectoderm black, the entoderm dotted and the mesoderm lined.

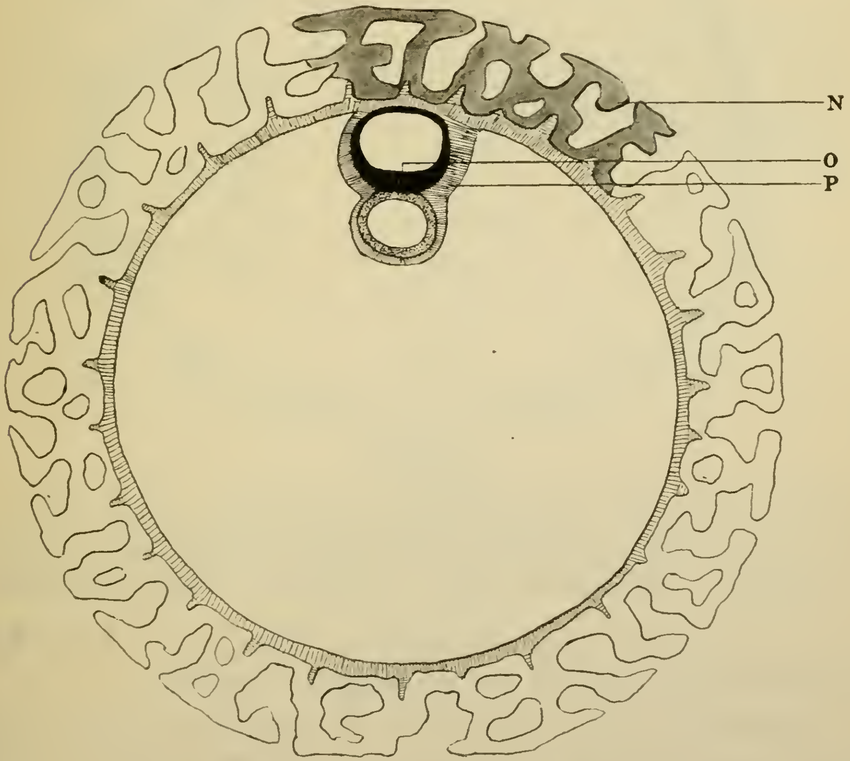


FIG. 227.—n, The trophodermal villi penetrated by the chorionic mesoderm, representing the chorionic villi; o, embryonic shield; p, beginning body-stalk.

cavity, that within the entoderm the *enteric* and that within the mesoderm (extræmbryonic) the *celom* (C, Fig. 226). The cavities are filled with liquid and the entire structure is called the **triploblast** or **blastodermic vesicle**. During these internal changes the trophoderm has become thickened and the zona pellucida, having performed its function, has disappeared. The ovum has become implanted and is covered by the decidua capsularis.

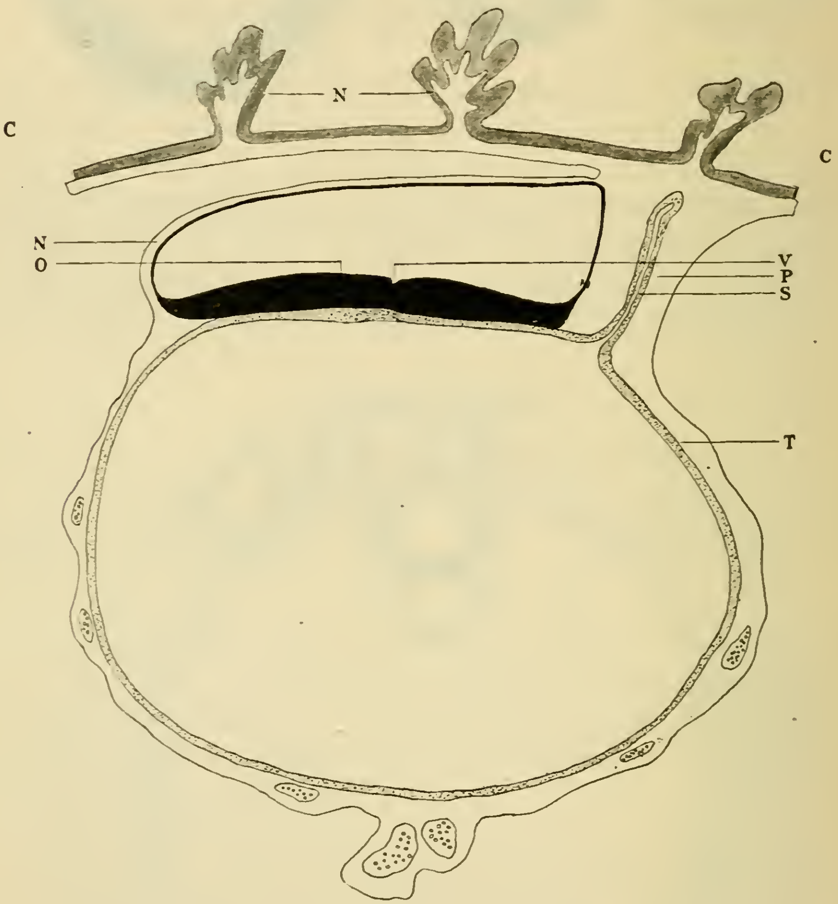


Fig. 228.—n, Chorionic villi; o, embryonic shield; p, body-stalk; n, amnion; s, allantois; t, yolk-sac with vessels; v, blastopore. Mesoderm unmarked.

In examining C, Fig. 226, it will be seen that at first the ectodermal roof of the amniotic cavity is in continuity with the trophodermal cells. The floor of the amniotic cavity is called the *embryonic shield*, or *button* and in this area alone the embryo is developed.

Fig. 227 show that the mesoderm has separated the ectoderm from the trophoderm and also that the mesodermal tissue of right wall of the amniotic cavity has been increased. This is of significance. Fig. 228 shows this latter tissue greatly increased forming what is called the *body* or *belly-stalk*. This stalk has become pronounced through the splitting of the mesoderm of the roof, this cleft extending all the way to the body-stalk (Fig. 228). This membrane (ectoderm and mesoderm) roofing the amniotic cavity is the *amnion*, the formation of which is not the same in all vertebrates. If the embryonic shield be examined it will be found to consist of ectoderm and entoderm in the embryonic area proper, the body mesoderm having as yet not been developed.

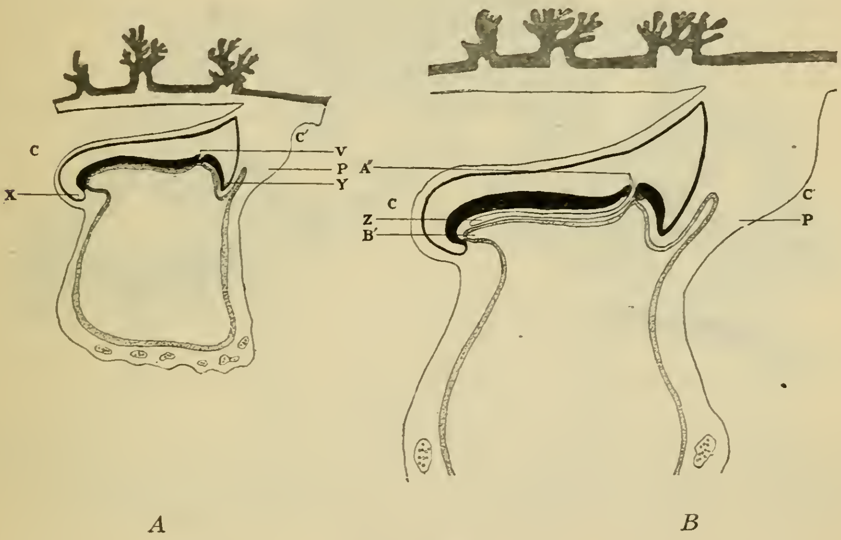


FIG. 229.

A—x, Head-fold of the amnion; y, tail-fold of the amnion; v, notochordal invagination (gastrulation) of ectoderm beginning. *B*—z, Notochordal canal. The space between the ectoderm and entoderm is exaggerated. a″, Group of ectodermal cells, around the blastopore, that gives rise to the body mesoderm.

If this area be viewed from the ectodermal (dorsal) side a linear groove extending over the greater part of the shield will be noted. This is the *neural* groove. This groove deepens, its dorsal lips meet and fuse and thus a tube of ectoderm, the *neural tube*, is buried beneath the ectoderm. From this tube the entire central nerve system is developed.

At the cephalic extremity (left in Fig. 229, A and B), of the embryonic area a slight transverse groove (x) appears called the *head fold of the amnion.* This marks absolutely the head limit of the embryo. At the caudal extremity (right in Fig. 229, A and B), a like groove (y) appears, the *tail fold of the amnion.* Two lateral linear grooves appear called the *lateral folds,* limiting the body laterally (Fig. 230, B and D). As those folds deepen and approach one

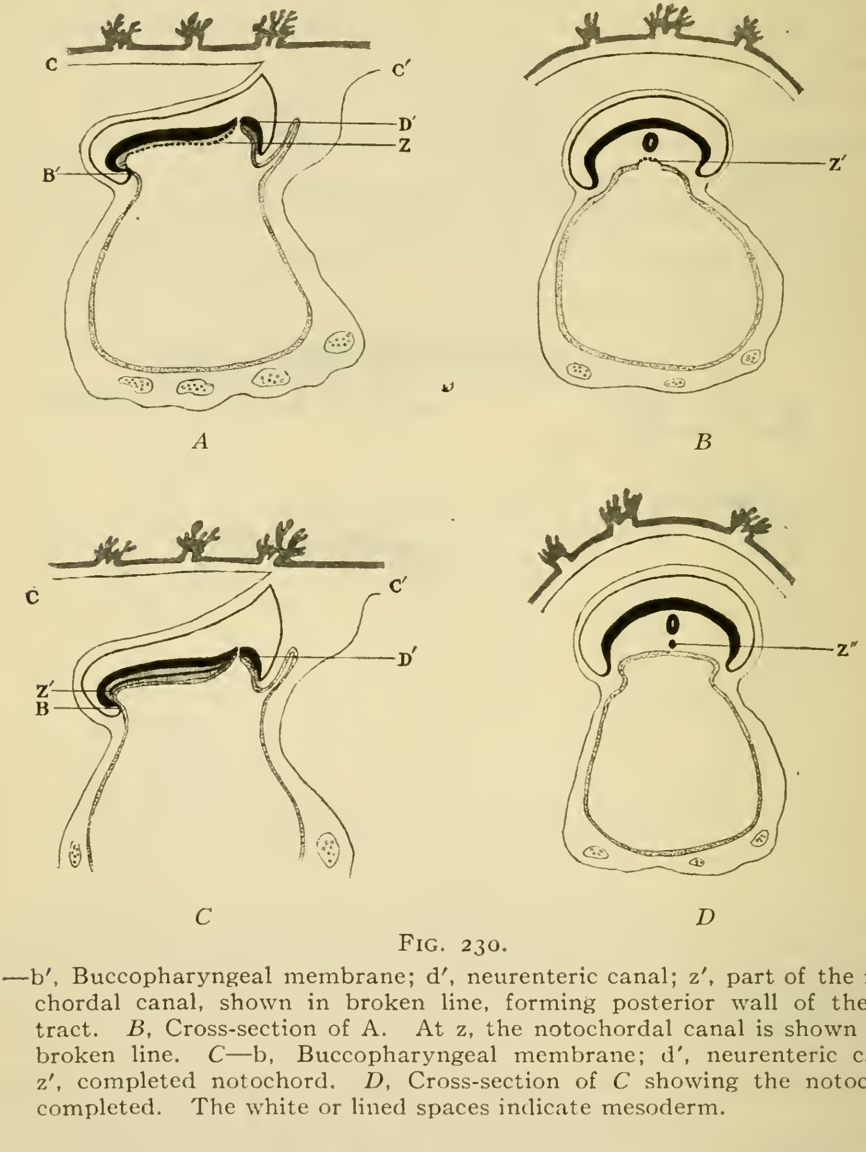


Fig. 230.

A—b′, Buccopharyngeal membrane; d′, neurenteric canal; z′, part of the notochordal canal, shown in broken line, forming posterior wall of the gut tract. *B*, Cross-section of A. At z, the notochordal canal is shown by a broken line. *C*—b, Buccopharyngeal membrane; d′, neurenteric canal; z′, completed notochord. *D*, Cross-section of *C* showing the notochord completed. The white or lined spaces indicate mesoderm.

another ventrally the body is completely outlined. The ectoderm and mesoderm form a layer called the *somatopleure* (Fig. 231), that gives rise to the amnion and body wall. The entoderm and mesoderm constitute a layer, the splanchnopleure, which gives rise to the gut-tract, yolk-sac, vitelline duct and allantois.

As seen in the foregoing the ectoderm, entoderm and extraembryonic mesoderm have been formed from solid masses by the disappearance of certain of their cells, or *delamination* as it is called. The body or intraembryonic mesoderm is formed in another manner. At the caudal end of the neural groove a small depression appears due to the cord-like invagination of ectoderm between ectoderm and entoderm. This is the *notochordal invagination* and this constitutes a modified *gastrulation* (Figs. 228 and 229). The mass of ectoderm continues to grow cephalad to within a short distance of the head end of the neural tube, to which it lies ventral. This cord becomes a tube by the disappearance of its central cells and then its ventral wall and the entoderm (against which it lies) both disappear, thereby (Fig. 230, A and B, *Z′*) making the notochordal ectoderm the dorsal boundary of the enteric cavity, and leading former observers to believe that the notochord arose from the en-

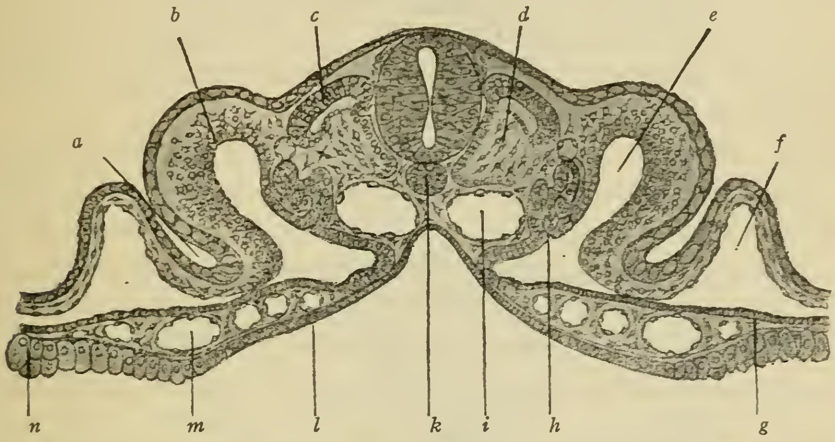


Fig. 231.—Section of a Chick Embryo with Eight Segments. (*Balfour.*)

a, lateral fold of the amnion; *b*, somatopleuric mesoderm; *c*, muscle plate; *d*, mesoderm of somite; *e*, intraembryonic celom; *f*, extraembryonic celom; *g*, splanchnopleuric mesoderm; *h*, primitive kidney anlage; *i*, aorta; *k*, notochord; *l*, entoderm of gut-tract; *m*, vessel; *n*, entoderm of yolk-sack.

toderm. Soon the notochordal ectoderm folds off from the entoderm forming a solid cord (Fig. 230, C and D, Z'') the *notochord proper.* When the notochordal cavity became continuous with the enteric cavity this later cavity communicated with the amniotic cavity through notochordal depression; this short canal is called the *neurenteric canal*, because the neural tube ultimately closes off the amniotic connection and then the canal leads from the neural canal into the enteric canal.

As the notochordal invagination is formed other ectodermal cells are set aside here between ectoderm and entoderm. These begin to multiply rapidly forming an entirely different group of cells that spread in all directions between ectoderm and entoderm, constituting the *body mesoderm* that soon connects with the extra-embryonic mesoderm.

By this time, the ovum has become lodged in the uterine mucosa. This process is accomplished by the aid of the trophodermal cells, that have the power of *phagocytosis* (destruction of tissue) and erode the superficial tissues of the mucosa, forming a cavity into which the ovum sinks. The trophodermal layer has become increased in thickness. The epithelium of the uterus is lost in this region and also in the glands and the superficial vessels are exposed. The trophoderm, or *placentoblast* becomes altered as follows: Cells vacuolate and disappear at irregular intervals leaving a fringe of epithelial villi, the *trophodermal villi.* As a result, there are formed a series of intercommunicating spaces, the *trophodermal lacunæ.* According to some the trophoderm first consists of two layers of cells. These increase in an irregular manner forming little finger-like projections, the *trophodermal villi.* When these become invaded by the mesoderm they constitute *chorionic villi.* The villi are composed of trophoderm and mesoderm. When the vessels of the mucosa are exposed, they rupture into the glandular spaces, and from these, the maternal blood gains access to the *trophodermal lacunæ,* or spaces. Thus does the embryo receive nourishment from the mother, before the umbilical vessels are present. The area of the ovum left uncovered when the ovum becomes lodged, is covered by mucosa that is reflected from the lining at the sides of the ovum. This is, therefore, called **decidua capsularis** or **ovular decidua.** The trophodermal villi soon receive a core of mesoderm and are then called *chorionic villi*, the whole membrane being termed the *Chorion*.

We must remember that the **belly-stalk** connects the embryo with the chorion. This belly-stalk is of importance, because it presents that part of the embryonic disc that does not lose connection with the prochorion during the formation of the body-wall and gut-tract. Into the belly-stalk the allantoic evagination of the gut-tract extends for a short distance, while the allantoic vessels pass along the entire extent of the stalk to the forming chorion. With the passage of the allantoic vessels to *vascularize the chorion, the belly-*

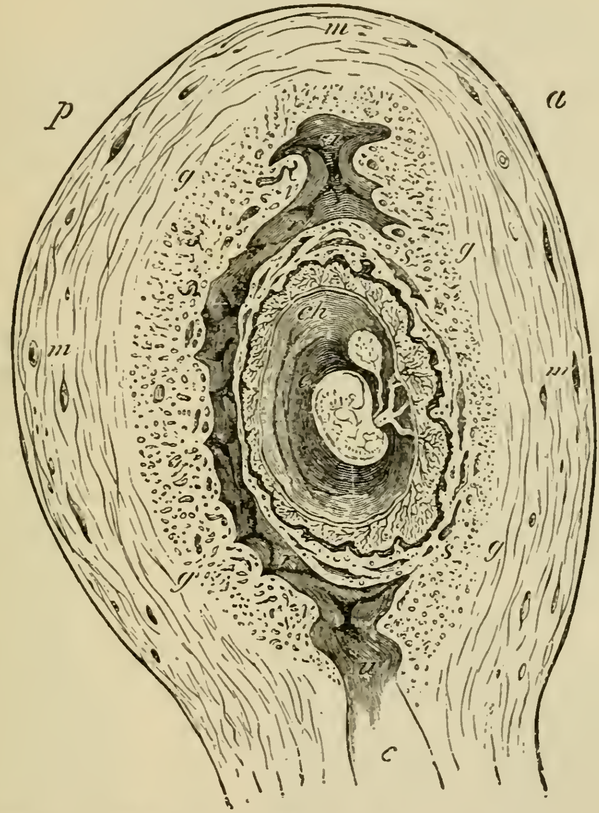


FIG. 232.—SEMI-DIAGRAMMATIC OUTLINE OF A DORSO-VENTRAL SECTION OF A HUMAN UTERUS CONTAINING AN EMBRYO OF ABOUT FIVE WEEKS.

a, Ventral; *p*, dorsal surface; *g*, outer limit of decidua; *s*, *s*, limits of the placental decidua; *ch*, chorion, within which is the embryo enclosed by the amnion, and attached to the chorion by the umbilical cord; from the cord hangs the pedunculated yolk-sac; *r*, *r*, ovular decidua. (*Minot.*)

stalk becomes the so-called extraembryonic portion of the allantois. In some animals, the **oviparous,** the allantois develops as an independent sac there being no belly-stalk in those forms. It remains as a dilated sac, and serves as a receptacle for urine. In the **viviparous** animals, it *remains connected with the belly-stalk, and is said to connect the embryo with the uterus,* becoming the *organ of nutrition and respiration. As a matter of fact, it is the belly-stalk that forms the link between fetus and chorion;* the chorion becomes the fetal portion of the placenta, while the belly-stalk becomes the umbilical cord by the addition of the vessels. It would seem that the *allantois proper has nothing to do with the formation of the placenta and cord in the higher types.* In this mesoderm, four main vessels develop, *two arteries* and *two veins.* Later but one vein is found, due either to a fusion of the two veins, or probably to the *atrophy of the right vein.* The two veins enter the body and proceed toward the heart, while the other two vessels pass into the body, and connect with the aorta. The distal ends of all the vessels pass into the chorion, and divide to ramify all the villi. These villi are still covered by the trophoderm, consisting usually of two layers. Of these, the outer becomes converted into a thin layer of protoplasm, in which the original nuclei remain and the cell-boundaries are lost. This protoplasm constitutes the **syncytium.**

The villi do not remain simple, but branch and rebranch; the vessels follow these branches, and penetrate to the very ends. Some of the villi enter the uterine glands, in which the epithelium becomes denuded by about the sixth week, and the surface cells by the fourth week, and are the *floating villi;* others become attached, and form the *fixed villi.* When the epithelium of the uterus is lost, the engorged superficial capillaries of the placental decidua become connected with the glands, and the blood enters these, and then the trophodermal spaces. These channels are the later *intervillous spaces.* From these cavities, the blood is returned to the venous channels of the mucosa, but no *direct connection is established between the fetus and the mother.*

These villi are very abundant, and may be scattered all over the ovum or be limited to the equator of the mass. Up to this time, all are equal in size. Soon a difference is noted in size, those at the place of attachment of the ovum increase in number and size, forming the *chorion frondosum* (the later placenta), while the remainder disappear and constitute the *chorion læve.* The latter do not become vascularized.

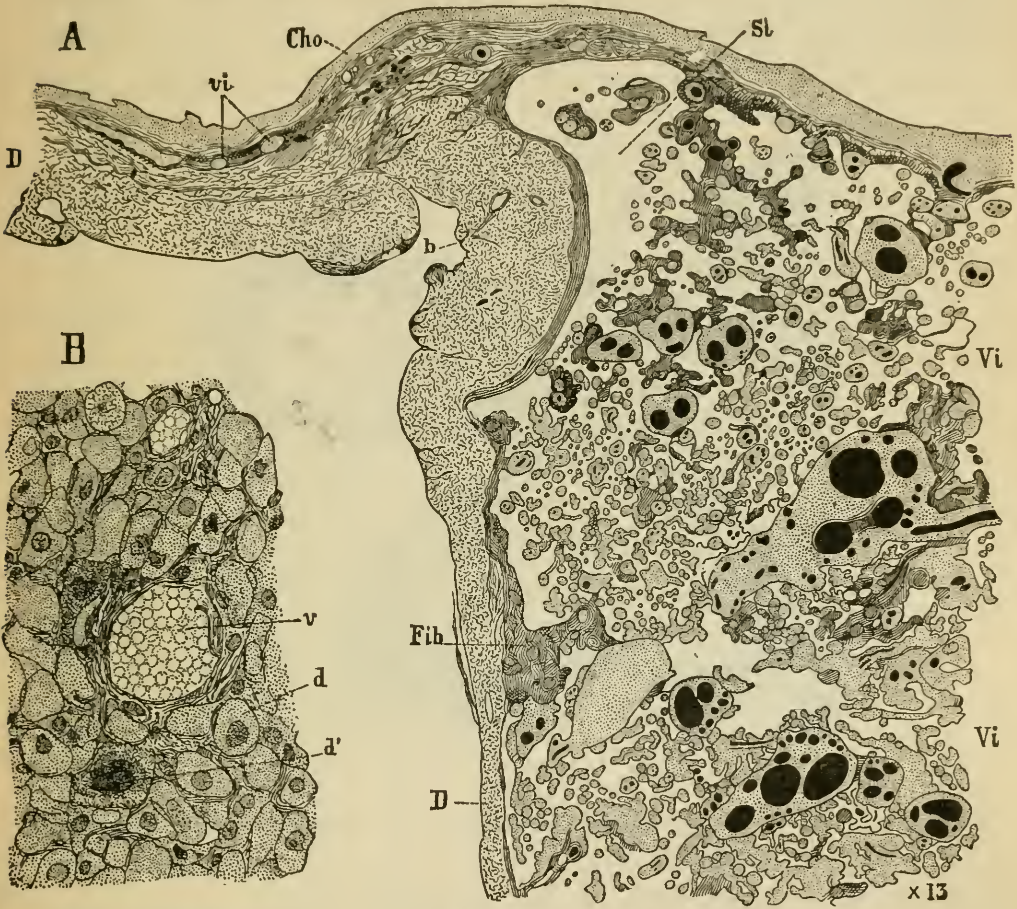


FIG. 233.—HUMAN PLACENTA AT TERM.

A, Vertical section at margin; *D*, decidua; *Cho*, chorion; *Fib*, fibrin; *Vi*, placental villi; *Si*, marginal sinus; *vi*, aborted extra-placental villi; *b*, decidual tissue. *B*, Portion of decidual tissue at *b* highly magnified; *v*, blood-vessels; *d*, decidual cells with one nucleus; *d'*, multinucleated decidual cells. (*Minot.*)

At about the fifth month, a villus has the following appearance. Of the trophodermal cells, the outer do not remain large, distinct elements, but become flattened, and represent a mere layer of nucleated protoplasm that covers the villi; this is the *syncytium*, and it is the covering of the embryonic connective tissue that constitutes the core of the villi and supports the vessels. In the inner layer, the cells remain distinctly outlined, and persist for a short time as the *cell-layer of Langhans.* From the fifth month on, this layer disappears so that ultimately only the syncytium remains. Here and there on the villi are seen groups of cells that represent collections of syncytial cells, the *cell knots.* These, like the other syncytium, contain nuclei that are small, but stain deeply. The cytoplasm responds well to the acid stains. The Langhans cells, however, contain large nuclei, but neither these nor the cytoplasm respond well to stains.

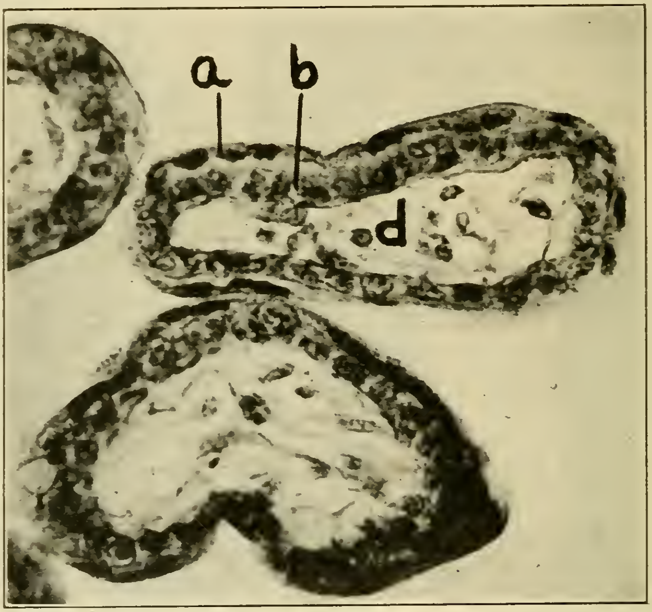


FIG. 234.—CROSS-SECTION OF SOME VILLI OF THE PLACENTA AT THE FIFTH MONTH.

a, Syncytium; *b*, cell layer of Langhans; *d*, mesenchymal core of villus. (Photograph. Obj. 4, mm., oc. 5 X.)

After the third month, the number of villi that becomes attached to the mucosa rapidly increases, so that after that time the fetal and maternal portion become more and more fixed to each other.

This is the beginning of the formation of the placenta as it is seen at birth. The villi branch repeatedly, and the whole structure grows rapidly, causing the child to do the same. Any disturbance that will retard the growth of the placenta will also retard the growth of the fetus in greater proportion. The difference between the placenta at the fourth or fifth month and at birth is merely in size. This is due to the increase in number and branches of the villi. The villi are separated into groups by connective tissue septa that are derived from the uterine tunica propria. These are the *placental septæ* and they contain the *decidual cells.*

At birth the **placenta** is a flesh-like, saucer-shaped mass, the attached surface of which is divided into lobes, or *cotyledons.* The fetal surface is covered by the amnion, a continuation of the sac in which the fetus lies, and shows the vessels as they enter and leave the organ; the opposite surface is divided into lobes, or cotyledons, covered by the decidua basilaris. The weight of the placenta is from 500 to 1200 grams, averaging about one-sixth that of the child. It consists of two portions, the fetal and maternal.

This organ consists of a fleshy mass lying between two membranes. Upon the fetal surface, we find the **amnion** and **chorionic mesoderm.** The **amnion** consists of a single layer of cuboidal epithelial cells that rest upon the mesodermal tissue. These epithelial cells possess prominent, deeply-staining nuclei, but the cytoplasm does not react well to the stain. The mesodermal tissue is somewhat fibrillar, and few cells are present. It is avascular.

The **chorionic mesoderm** is composed of mesodermal tissue in which the fibrils are more or less distinct. This mesoderm is covered by trophodermal (ectodermal) cells that later become the syncytium. From the side opposite to the amnion are seen projections. These may vary from small simple villi to those resembling a tree possessing an enormous number of twigs. Along this surface of the chorion, may be seen masses of a fibrillar substance that are called *canalized fibrin.* The bulk of the placenta consists of *villi.* These form a reddish spongy mass, divided into masses called *cotyledons.* The main stems contain two or more vessels surrounded by mesodermal tissue. Peripherally, each villus is covered by a thin layer of nucleated protoplasm, the *syncytium.* The small twigs consist of a core of mucous connective tissue supporting several small capillaries. The syncytium surrounds each twig. In places are seen collections of nuclei representing the *cell-knots.* The cavities between the villi are the *intervillous spaces* containing the maternal blood and, at times, canalized fibrin.

From this, it is readily seen that the *fetal and maternal blood currents do not intermingle.* They are separated from each other, the endothelium of the fetal capillaries on the one hand, and the syncytium of the villi on the other.

The maternal side of the placenta is covered by the **decidua basalis,** or the **stratum compactum** of the mucosa. It is less than a millimeter thick, and possesses a number of short oblique channels. These are the remains of the uterine glands; they now represent *blood sinuses,* which contain maternal blood.

The basalis extends into the fetal portion as the *placental septæ,* and divides it into the cotyledons. At the edge of the placenta, it becomes attached to the chorion, and continues as the **decidua parietalis.** At this junction there is a considerable space that extends all around the edge of the placenta. This is the *marginal sinus,* and is prominent because few or no villi have developed here.

The **membranes** consist of the **amnion** and the uterine lining, or the **stratum compactum.** The *latter* is thin, and contains neither glands nor epithelium. When the fetus increases in size and causes a dilatation of the uterus, the amniotic sac is forced against the uterine lining, and causes an atrophy of the glands and cells of the stratum compactum. As a result, a mere fibrinous membrane, that has a loose connection with the amnion, is produced, due entirely to pressure.

Fossati, by means of the Golgi method, found a peculiar network of fibers surrounding the blood-vessels of the placenta and umbilical cord; this network also seemed to come into relation with the epithelium. *He considered this network nerve tissue.*

There are four varieties of placentæ: (1) **Villous,** in which the villi simply fit into the uterine glands, as in the pig and armadillo. (2) **Cotyledonary,** in which the placenta consist of many scattered button- or ring-like masses, as in the cow, horse, camel and sheep. (3) **Zonary,** in which the placenta is a band-like mass surrounding the uterine tube transversely, as in the cat and dog. (4) **Discoidal,** in which the placenta is a discoidal mass, as in man and rodents.

The **umbilical cord** is the connecting link between the fetus and the placenta, and represents the early belly-stalk. It is peculiarly twisted and may even be knotted. It is surrounded by one or more layers of cuboidal epithelial cells, continuous on the one hand with epithelium of the amnion, and on the other with the ectodermal cells of the body, supported by a little subepithelial fibrous tissue. Within this covering is the peculiar tissue called **Wharton's jelly.** This is embryonic connective tissue in which the cells are chiefly spindle-shaped; some round and stellate cells, however, are seen. The intercellular substance is semi-solid, and takes a peculiar homogeneous stain. During the early months of pregnancy, the intercellular substance contains a great deal of water, and the cellular elements are few. At the end of pregnancy the intercellular substance is somewhat fibrillar, though the semi-solid portion predominates. At this time the cells are mostly of the stellate type, but not numerous. At the body end, occasionally, traces of allantoic cavity and yolk sac are found.

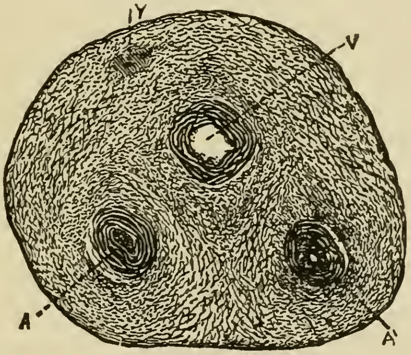


FIG. 235.—CROSS-SECTION OF HUMAN UMBILICAL CORD. (*Minot.*)
A, *A'*, Umbilical arteries; *V*, umbilical vein; *Y*, remains of allantois.

The **vessels** contained are the *single* **umbilical vein** and *two* **umbilical arteries.** These are all thick-walled and well-developed, and the muscle fibers run both circularly and longitudinally. The wall of the arteries is thicker than that of the vein. The insertion of the cord into the placenta is usually *eccentric*, and at this point the vessels branch rapidly and spread out in all directions.

The *circulation* of the placenta is a *closed one.* The blood is carried from the iliac arteries to the umbilicus through the *hypogastric arteries,* which continue in the cord as the *umbilical arteries.* These branch to follow the villi and ultimately terminate in tufts of capillaries in the terminal villous twigs. The blood at this point receives the oxygen and nutritive matter from the maternal blood that circulates in the intervillous spaces in which the villi lie. There is *no direct communication between the fetal and maternal blood*, for they are separated from each other by the endothelium of the capillaries and the syncytium covering the villi. As the oxygen and nutritious substances pass into the fetal blood, the effete matter and gases pass out into the maternal blood. The principle is the same as in the lung, where the blood is oxygenated. Red cells never pass from one system to another, but leukocytes that have the power of ameboid motion may. The blood is collected by the radicals of the *umbilical vein* and carried into the body to the under surface of the liver, where a portion enters the portal vein through the continuation of the umbilical vein, is distributed to the liver and collected by the hepatic veins and emptied into the postcava; the remainder is carried to the postcava (inferior vena cava) by the *ductus venosus*. The blood passes to the right atrium, then through the *foramen ovale* to the left atrium, from which it passes, through the atrioventricular orifice, into the left ventricle. The blood then passes into the aorta chiefly to the upper extremities and head, is collected by the radicals of the precava (superior vena cava), and emptied into the right atrium. From this chamber it passes through the atrio-ventricular orifice into the right ventricle, from which it passes into the pulmonary artery toward the lungs. As these organs do not functionate at this time, most of the blood is sent to the aorta through the *ductus arteriosus*. The blood then passes toward the lower extremities, and, as it reaches the internal iliac arteries, most of it is sent to the placenta through the arterial trunks, which inside of the body are called the *hypogastric arteries*, and in the cord the *umbilical arteries*.

CHAPTER XVI

THE SKIN AND ITS APPENDAGES

The **skin** covers the external surface of the body and is its most extensive organ. It varies in thickness in the different parts; upon the medial surfaces of the extremities it is thinnest and gradually increases in thickness over the thorax, abdomen, lateral surfaces of the extremities, back, buttock, palm and sole.

It consists of two portions, the **epidermis,** or **cuticle,** and the **cutis vera,** or **corium.** The epithelial portion is the protective part while the connective tissue derma is the vascular portion and also contains the accessory structures. The skin besides being protective is also very sensitive; in the derma are the tactile organs and various other sensor nerve organs for the perception of general sensations, pain and temperature changes. It is also an important excretory organ and maintains, or regulates body temperature. It has a number of different appendages. The *hairs* serve as a protection and are not evenly distributed, as will be seen later. The *sebaceous glands* secrete an oil that serves to keep the skin pliable and tends to keep the hairs soft and flexible. The *sweat glands* have a double function; they are excretory glands and are assistants to the kidneys. The perspiration also serves to regulate the body temperature. The *nails* are protective. These appendages lie wholly or nearly so, except the shafts of the hairs, within the vascular derma.

In general *pigment* is lacking in the skin of the Caucasian except around the nipples and genitalia and in those individuals who live in the tropical and subtropical regions. Pigment is deposited in those individuals as a protection against the actinic rays of the sun. The general pinkish color is due to the vascularity of the derma and the thicker the epidermis the lighter the color. The skin is continuous with the mucous membranes of the body at the various orifices of the various tracts, as the oral and nasal apertures and the anal and urinogenital orifices. At these *mucocutaneous junctions* the skin is more delicate and more vascular and the transition from skin to mucous membrane is sharp and distinct.

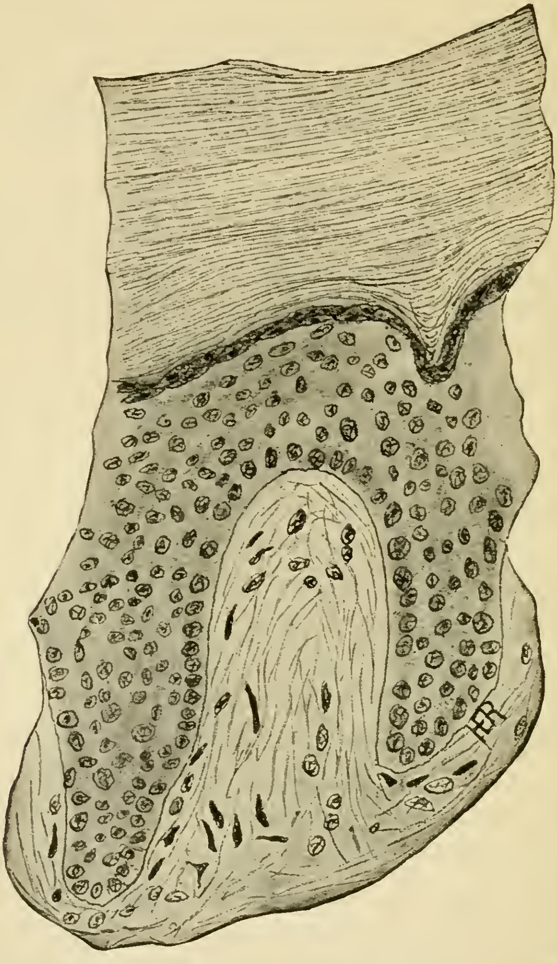


FIG. 236.—SKIN OF THE PALM OF A CHILD AT BIRTH SHOWING STRATIFIED SQUAMOUS EPITHELIUM. (*Radasch, Reference Handbook of the Medical Sciences.*)

The **epidermis** is the epithelial portion of which the appendages are modifications. It varies in thickness from 0.03 mm. to over 1 mm. in different parts of the body. This is in direct proportion to the amount of mechanical disturbance to which the part is subjected. It consists of *stratified squamous* cells, which, over the general body surface, are divisible into *two layers*, **stratum Malpighii** and **stratum corneum.**

The **stratum Malpighii,** or **rete mucosum,** is composed of a number of layers of cells. The basal part consists of columnar elements, and is called the **genetic layer.** The cells stain deeply, and under certain conditions show pigment granules. The layer is uneven in its course, as it conforms to the waves of the corium. The upper cells of the stratum Malpighii are large polyhedral elements that do not touch one another, but are separated by intercellular spaces. These spaces form an extensive area for the diffusion of lymph and are bridged by delicate cytoplasmic processes that extend from one cell to another. This is sometimes called the *stratum spinosum.* These are prickle cells that are also seen in other stratified layers. As the upper part of this stratum is approached, the cells become flattened and have an even course. Very often the uppermost layers of cells contain granules constituting the *stratum granulosum* to be described later.

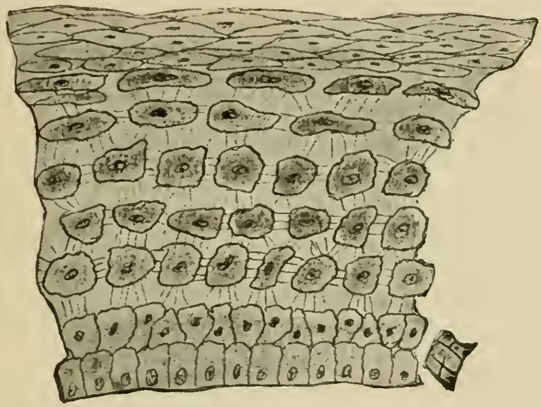


FIG. 237.—STRATIFIED SQUAMOUS CELLS SHOWING PRICKLE CELLS. (*Radasch, Reference Handbook of the Medical Sciences.*)

The **stratum corneum** ordinarily forms a thin layer. Its cells are very thin and scale-like and usually possess no nuclei. They are derived from the cells beneath, but differ from them in consisting of *keratin*, or *pareleidin*, that gives them their hard and horny characteristic. This substance is shiny and highly refractile, and does not respond readily to ordinary stains. These cells are constantly cast off, and the cells below increase to replace them. The cells of the lower layers acquire a distinct exoplasmic zone, the prickles become shorter and thicker and the nucleus shrunken and dried.

Over the general cutaneous surface the cells of the stratum corneum are scale-like and no longer resemble cells. When treated with a solution of potassium hydroxid they swell and appear vesicular. Upon the sole and palm the cells of the stratum corneum are larger and appear swollen. They represent the epitricheal cells of the fetus which seem to persist in those parts devoid of hairs.

In certain parts of the body, sole and palm, the **stratum granulosum** and another, the **stratum lucidum**, are well developed.

The **stratum granulosum** lies exernal to the stratum Malpighii, and is composed of two or three layers of flattened, spindle-shaped cells that contain a deeply staining nucleus and coarsely granular cytoplasm. The *granules* are *keratohyalin* that later form the horny matter of the stratum corneum. This substance is peculiar to mammals. These granules are quite large and prominent, and respond well to hematoxylin as it is strongly basophilic. They seem to be modified cytoplasm, but some hold that they represent products of the nucleus but not chromatin.

The **stratum lucidum** lies external to the stratum granulosum, and separates this from the stratum corneum. It forms a narrow, glistening band of cells, two or three layers broad, in which the *keratohyalin* granules have fused to form a homogeneous substance, called *eleidin*. In the stratum corneum these granules become *pareleidin;* this will blacken slowly in osmic acid due to the oil from the glands, not fat in the cells. This substance reacts well to eosin. The nuclei are not prominent nor are the cell-bodies distinct. This layer is absent where the skin is thin.

As the cells of the stratum corneum are constantly desquamating they must be replaced. This is brought about by active karyokinesis of the cells of the stratum Malpighii.

In injuries to the skin where the epidermis is lost the stratum Malpighii at the margins of the area gradually extend onto the injured area and from this extension the special layers are later derived. When the denuded area is great skin-grafting is employed.

In this each minute graft represents a little island from which the stratum Malpighii spreads in all directions and the denuded area ultimately becomes entirely covered if the work is successful.

The **derma, true skin,** or **cutis vera,** is composed of connective tissue arranged in two or more less distinctly separated layers.

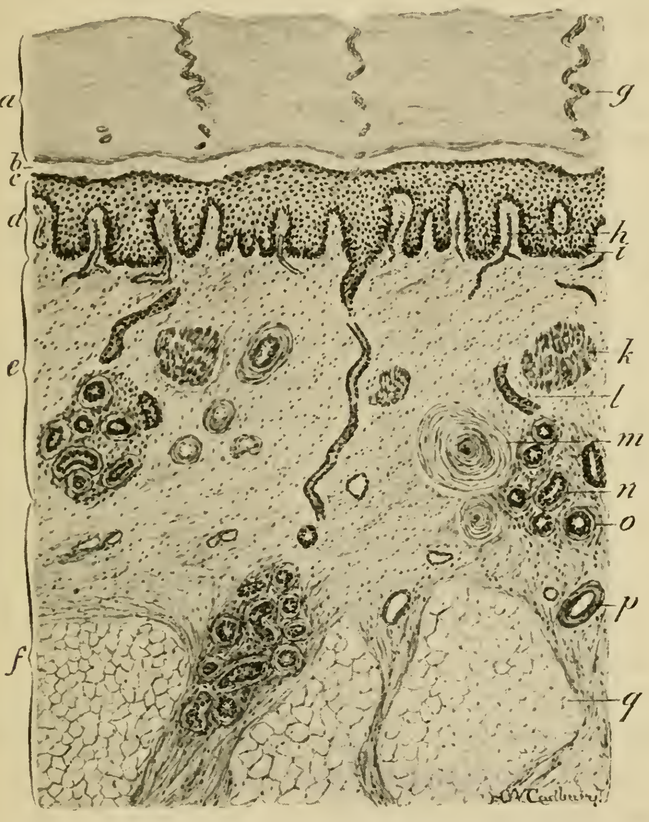


Fig. 238.—Cross-section of Skin of Sole of Foot.

a, Stratum corneum; *b*, stratum lucidum; *c*, stratum granulosum; *d*, stratum Malpighii; *e*, derma; *f*, panniculus adiposus; *g*, duct of sweat gland; *h*, prickle cells; *i*, genetic layer; *k*, cross-section of a smooth muscle fiber; *l*, duct of sweat gland; *m*, Pacinian body; *n*, secretory portion of sweat gland; *o*. muscle of tubule; *p*, blood-vessel; *q*, adipose tissue.

These are the **stratum papillare,** or *outer,* and the **stratum recticulare,** or *inner*.

The **stratum papillare** consists of delicate bundles of small white fibrils forming a close network with elastic fibers.

The upper portion of this stratum is thrown into small waves called the *papillæ,* to which the stratum Malpighii conforms. Over the general skin surface, these papillæ do not extend through the stratum Malpighii, but in the *palmar* and *plantar* regions they are visible externally, and assist in forming the peculiar markings seen in these areas. These papillæ are important, as they contain *either capillary plexuses* or *special sensor nerve organs.* These are the *vascular* and *tactile papillæ,* respectively. The lower portion of the papillare consists of a looser network, in which the vessels form plexuses parallel with the surface. It gradually passes into the **stratum reticulare**. These papillæ are tallest and most numerous in the palmar and plantar regions, poorly developed in the skin of the face and here tend to disappear in old age. In the palmar and plantar regions there are usually two papillæ under each ridge.

The **stratum reticulare** is not distinctly separable from the preceding. It is composed of larger bundles of coarser fibrils of white fibrous tissue, and contains some yellow elastic tissue, as will be seen below. Here are found the larger blood-vessels and the appendages and special sensor nerve beginnings. In the corium of the scrotum, penis and nipple, smooth muscle fibers are found. When these bundles contract, "goose-flesh" is produced. In the skin of the face and over joints elastic tissue is most abundant. It decreases everywhere with old age.

The elastica is often separated into layers, of which there are four, the *subepithelial, papillary, reticular* and *subcutaneous* elastic layers. In the scrotum they form a membranous layer.

The derma varies in thickness from 0.5 mm. to 5 or 6 mm.; the latter measurement represents that of the derma of the back and shoulders. Here this layer is quite dense and many of the bundles of white fibrous tissue pass vertically through it to the panniculus adiposus.

Beneath the stratum reticulare is the **subcutaneous tissue,** or **panniculus adiposus**. This varies in thickness and density in the various parts of the body and the amount of fat is also variable. It connects the skin to the deep or muscle fascia and its mobility varies. It consists of bundles and septa of coarse white fibrous tissue forming meshes that contain the adipose tissue. The latter is usually in the form of lobules of different sizes. In some regions of the body the bundles course nearly parallel to the skin and here the meshes are larger and the skin is more mobile. Where the bundles are more vertical the skin is more firmly held. In addition to the cutaneous nerves and vessels this layer contains the roots of the larger hair follicles, and the larger sebaceous and sweat glands. Häggquist has described a thick bundle of smooth muscle tissue at the boundary zone between the stratum reticulare and subcutaneous tissue in those regions called *cold spots* and not elsewhere. By the reflex contraction of this muscle the adjacent blood-vessels are constricted when the skin here is subjected to a cold object.

Very little elastic tissue is present in this layer and granules have been found in the corium. In the white races, this pigmentation is limited to the nipple and genital region. In the colored races the amount of pigmentation gives the varying degrees of depth of color. In the lighter individuals the pigment (*melanin*) is limited to the lower layers of the stratum Malpighii but as the color deepens not only is there more pigment but more layers, higher up, are involved and the connective tissue cells of the derma will contain increasing amounts of pigment.

In the colored races the pigmentation of the skin is not manifested for several days after birth, although the pigment is present for several weeks before birth. Whether the pigment is due to the vital activity of the cells, or whether it is brought here and deposited, is not definitely settled. The former seems to be the origin of that of the retinal cells and probably of that of the skin. Recently it has been found that the pigment is of nuclear origin. This *pyrenoid substance* arises in the nucleus, passes through the nuclear membrane into the cytoplasm and here differentiates into *melanin*. It seems to be the result of the action of *tyrosin*, or *chromogen* of the cytoplasm, upon the *tyrosinase* formed by the nucleus.

The presence of pigment in the skin seems to be for the purpose of protection against the actinic rays of the sun. In the torrid regions where the actinic rays are most active Caucasians who are exposed to these rays very much soon become colored or tanned so that the exposed parts of the body no longer seem to belong to a Caucasian. This process occurs to exposed individuals even in the temperate regions, but to a lesser degree as the actinic rays here are not so powerful.

The skin is the protective organ, and varies in thickness in the different regions. It is thinner on the less exposed surfaces, as the inner surfaces of the thighs and arms, and thicker on the exposed regions, as back, sole and palm.

Upon the palmar and plantar surfaces the epithelium is thrown into ridges. These are arranged in definite patterns characteristic of each individual. Recorded impressions of these surfaces have been used as means of indentification for various purposes. Wilder considers the plantar patterns more characteristic than the palmar patterns.

These start to form in the eleventh week of intrauterine life and by the eighteenth week are visible upon the surface. These peculiar patterns remain permanent throughout life. Even though the epidermal surface may wear somewhat and scars may be present the general and special characteristics may still be made out as Galton has shown. These markings are present even in the skin of mummies and also in specimens preserved in jars. Under these extreme conditions they are still clear and distinct. Finger prints are now added to the Bertillon measurements in the criminal departments of all of the large cities and they have proved their value.

The *blood-vessels* of the skin vary in size and number, according to the location; in the gluteal, plantar and palmar regions, they are greater, while in the most movable parts they are most branched. The larger trunks lie in the lower part of the corium and form a plexus parallel to the surface. This plexus supplies the fat and sweat glands. Other branches pass to the superficial part of the corium, anastomose and send terminal twigs to the vascular papillæ (*subpapillary plexus*) and to the hair sheaths and sebaceous glands. The hair papillæ receive independent branches. In the papillæ the vessels continue as venous capillaries, that form a plexus just beneath the papillæ (*subpapillary plexus*). This empties into another in the lower portion of the derma that cummunicates with a subdermal plexus; the latter lies between the derma and the panniculus adiposus, and its vessels possess valves.

The *lymphatics* of the skin consist of *superficial*, or *papillary* *plexus*, which receives the lymph from the spaces in the papillæ, and a *deeper*, or *subcutaneous plexus* that consists of larger trunks, that anastomose with the above, and communicate with the special plexuses of the appendages.

The long *nerve* trunks are found in the reticulare, and from these branches form a *subpapillary plexus*. Myelinated fibers extend toward the surface, and form the special organs.

The *sensor organs* are very numerous in the skin. These comprise the *free terminals*, or those in which the naked axis cylinder pierce the epithelial layer, branch and send these divisions between epithelial cells. The higher forms of beginnings comprise *tactile corpuscles of Meissner*, most numerous in the palmar and plantar skin of the fingers and toes (there is usually one corpuscle to every four papillæ; here a pad of tissue is found that corresponds to the "walking pads" of carnivors); *bulbs* of the conjunctiva and genitalia; *Pacinian bodies* especially in the palms and soles; and the *organs of Ruffini*, resembling the *neuro-muscular organs*. For a detailed description, see **Nerve Tissue** (p. 156). In addition, there is the usual nerve supply to the blood-vessels.

THE APPENDAGES

The **appendages** of the skin are the **hairs, nails, sebaceous, sweat** and **mammary glands.** These are all derived from the epidermis.

THE HAIRS

The **hairs** are protective organs limited to certain portions of the body. Hairs are absent in the sole, palm, glans penis, glans clitoris, prepuce, medial surfaces of the labia majora, lateral and palmar surfaces of the phalanges and the dorsum of all of the ungual phalanges. They are most numerous upon the scalp where they average from 200 to 300 per square centimeter. Here they are distributed in groups of three or five. The slope of the hair varies in different parts of the body. They seem to be arranged in lines that form whorls, making a general *hair pattern* over the body surface. Each consists of a **root**, that portion within the skin, and a **shaft,** that part seen above the surface.

The **root** is somewhat flask-shaped, the lower end being enlarged to form the **hair-bulb**. This, on its under surface, is indented and invaginated by a little mass of connective tissue, the **hair papilla,** that contains a small tuft of capillaries, upon which the nourishment of the hair solely depends. The root is surrounded by a condensation of the derma, in which the connective tissue bundles are arranged into two layers.

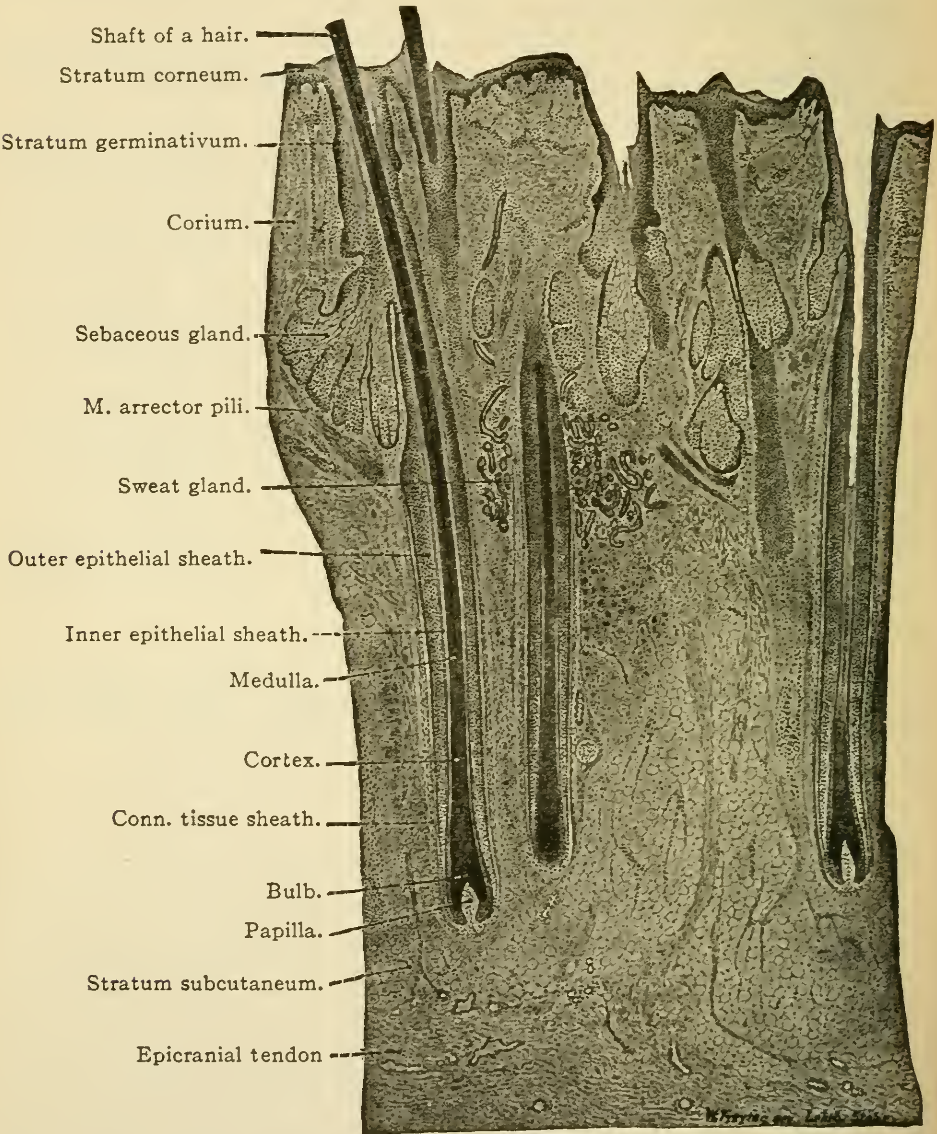

Shaft of a hair.
Stratum corneum.
Stratum germinativum.
Corium.
Sebaceous gland.
M. arrector pili.
Sweat gland.
Outer epithelial sheath.
Inner epithelial sheath.
Medulla.
Cortex.
Conn. tissue sheath.
Bulb.
Papilla.
Stratum subcutaneum.
Epicranial tendon

FIG. 239.—THICK SECTION OF THE HUMAN SCALP. × 20. (*Lewis and Stöhr.*)

In the *outer*, the fibers have a longitudinal course, while in the *inner*, they run circularly. The fibers of the *outer layer* interlace somewhat and are coarser than those of the inner layer. Capillaries and nerves are numerous but elastic fibers are few in number. The fibers of the *inner layer* also interlace to some extent and contain a rich capillary meshwork and many nerve fibers that form a plexus just beneath the epithelial layer. Within this circular layer is a prominent homogeneous band, the *glassy membrane*. This represents a greatly hypertrophied *basement membrane*. It is partly derived from connective tissue and partly from the exoplasm of the epithelial cells. Few connective tissue cells are present. These layers constitute the **follicular sheath.** Internal to it are found the epithelial cells, which are continuous with the epidermis. These are arranged into layers that are the **root sheaths,** of which there are two, **outer** and **inner.**

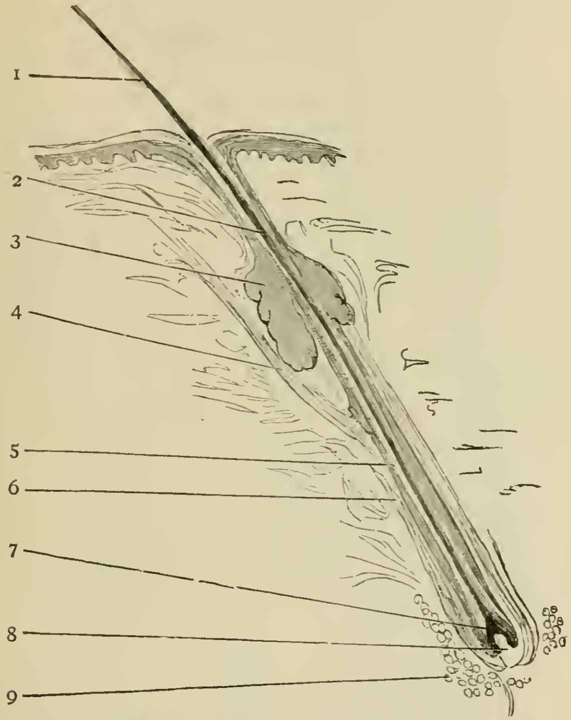


FIG. 240.—FROM A SECTION OF SCALP. (*Stöhr's Histology.*)
1, Hair-shaft; 2, hair-root; 3, sebaceous gland; 4, arrector pili muscle; 5, root sheaths; 6, follicular sheath; 7, hair-bulb; 8, papilla; 9, fat cells.

The **outer root sheath** is the direct continuation of the stratum Malpighii. These cells are the same as elsewhere, and continue to the bottom of the root, where they blend with those of the inner root sheath. Throughout the greater part of the follicle, this layer

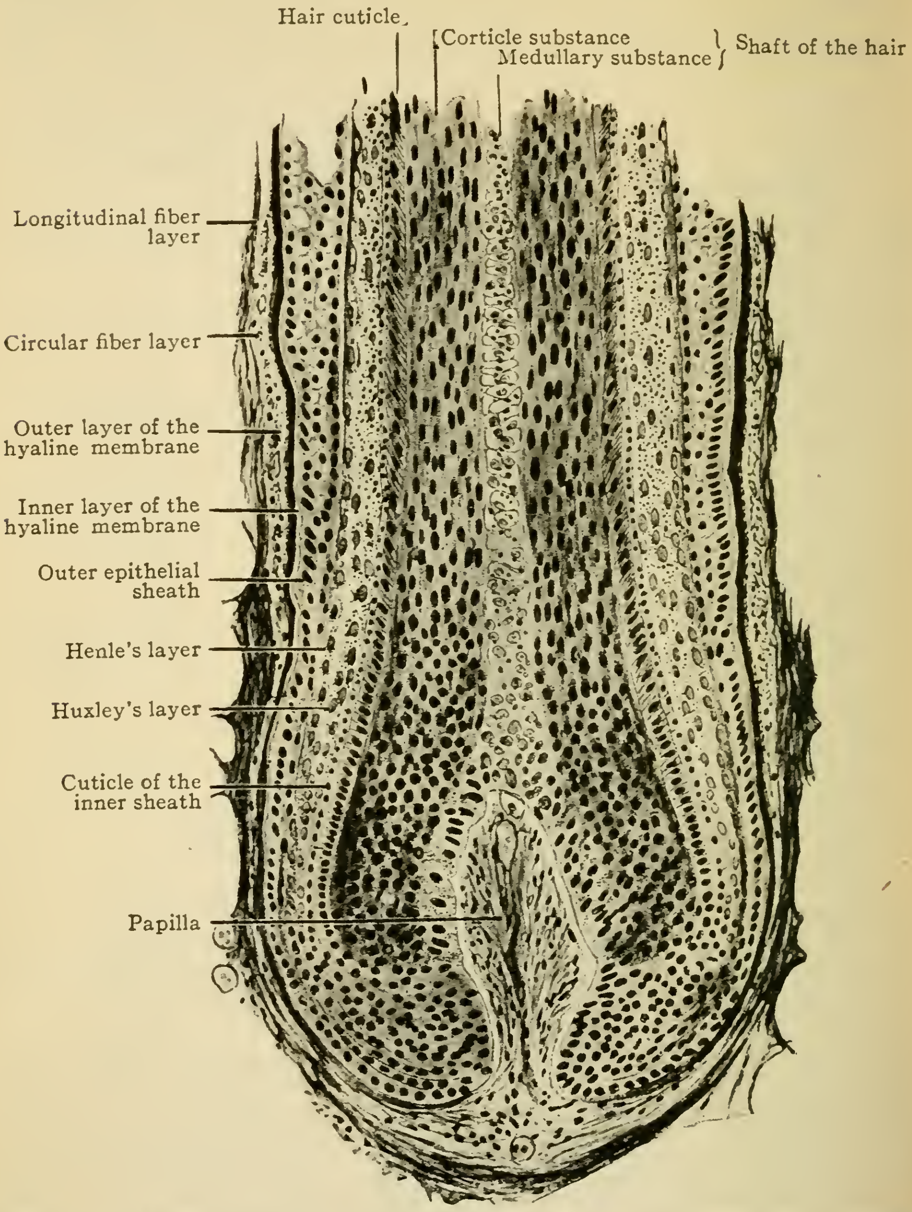

Hair cuticle
Corticle substance
Medullary substance
Shaft of the hair
Longitudinal fiber layer
Circular fiber layer
Outer layer of the hyaline membrane
Inner layer of the hyaline membrane
Outer epithelial sheath
Henle's layer
Huxley's layer
Cuticle of the inner sheath
Papilla

Fig. 241.—Longitudinal Section of the Lowest Part of the Root of a Hair. From a section of the human scalp. (*Lewis and Stöhr.*)

consists of several rows of cells. Toward the bulb, it gradually becomes reduced to a single layer.

The **inner root sheath** begins at the lower edge of the orifice of the sebaceous gland that opens into the hair follicle. Above the duct it is replaced by the stratum corneum. This sheath consists of two portions, the *outer* of which is called the **layer of Henle.** This lies next to the outer root sheath, and is composed of a single layer of flattened cells. The cells are clear and the nuclei are usually invisible. This layer is comparable to the stratum lucidum of the skin and may be absent or seem a part of the inner root sheath. Within this layer is the sheath, or **layer of Huxley,** which consists of two or three layers of large irregular cells. The cells are flattened and keratinized and correspond to the cells of the stratum corneum of the epidermis. It must be borne in mind that the structure of the root varies at different levels and in order to see all of the mentioned layers the section must be some distance from the bulb. In the bulb the root sheaths are no longer distinguishable as distinct

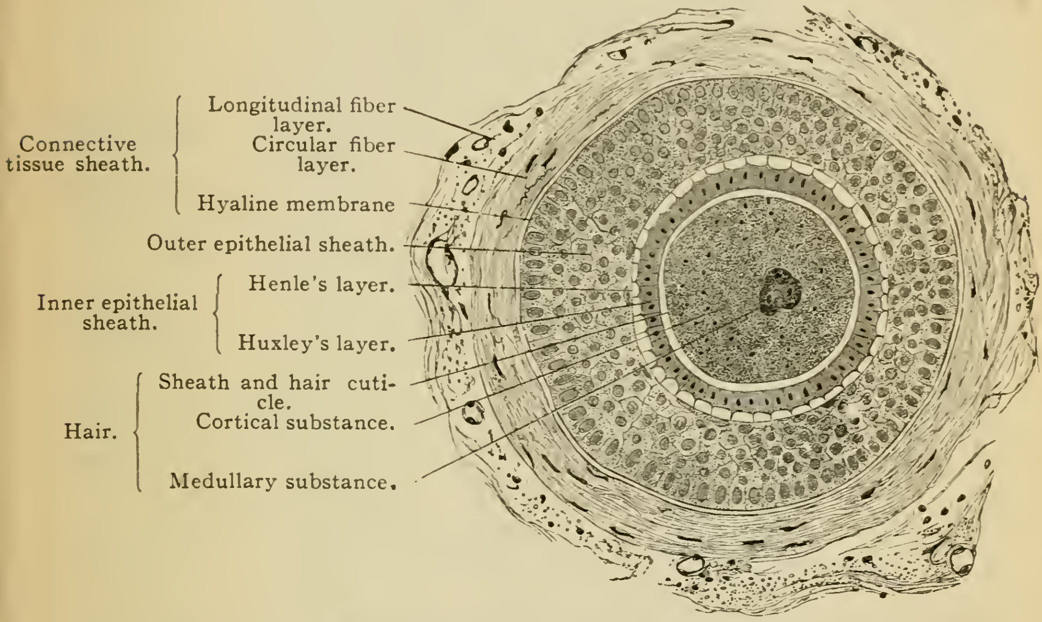

Connective tissue sheath.
Longitudinal fiber layer.
Circular fiber layer.
Hyaline membrane
Outer epithelial sheath.
Inner epithelial sheath.
Henle's layer.
Huxley's layer.
Hair.
Sheath and hair cuticle.
Cortical substance.
Medullary substance.

FIG. 242.—FROM A HORIZONTAL SECTION OF THE HUMAN SCALP. × 240. (*Stöhr.*)
Cross-section of a hair and its sheaths in the lower half of the root.

and separable layers but blend. Most of the cells represent the outer root sheaths which are the elements that really form the hair. Their great number cause the formation of the bulbous portion of the root. The cells here may often contain a large number of pigment granules.

The *hair papilla* is a club-shaped mass of delicate connective tissue from the derma in which the connective-tissue cells are very numerous. It contains a rich plexus of blood capillaries and also many nerve fibers that are no doubt trophic in function.

The **hair** occupies the central portion of the follicle, and is composed of three parts, **cuticle, cortex** and **medulla.**

The **cuticle** is composed of a single layer of irregular, nonnucleated scales. These are very thin and overlap. Within the follicle they lie closely applied to the layer of Huxley. These cells are thin and keratinized. The **cortex** consists of a great many layers of long, spindle-shaped elements. The nuclei are rod-shaped. These cells are keratinized and may contain pigment granules.

The medulla is absent in lanugo hairs and usually so in the hairs of the scalp. The **medulla,** when present, is composed of several rows of cuboidal cells that do not extend the length of the hair. They contain granules of keratohyalin, and frequently have a dark appearance; this is due to the presence of small air-bubbles.

The heaviest hairs are found on the scalp and pubis, in the axilla, and upon the face of males. Those of the scalp measure from 11 to 160 microns and those of the face up to 200 microns in diameter. Delicate hairs occur all over the body surface and measure about 5 microns in diameter; these are like the lanugo hairs of the fetus.

Light-colored hairs are finer than black hairs. The straight hairs are usually coarser and thicker than the crisp hairs and on cross-section are usually circular in outline. The crisp hairs are oval upon section and are most flattened in the Japanese, Chinese and Indians.

Shortly before and after birth there is a general shedding of the hairs. In adults this loss and renewal is constant. Scalp hairs are said to live 1600 days. The process of shedding is as follows: The hyalin membrane and circular fibers of the outer root sheath thicken, and the matrix ceases to produce an inner root sheath.

The bulb becomes cornified and frayed. The increase of undifferentiated cells forces the old hair and inner root sheath outward. The hair follicle collapses and shortens. Later the matrix cells proliferate, lengthen the follicle and produce a new hair.

The *color* of the hair is due to pigment granules in the cortex. These cells may even contain pigment in solution. Diffuse pigment is abundant in dark and red hairs, but absent in white.

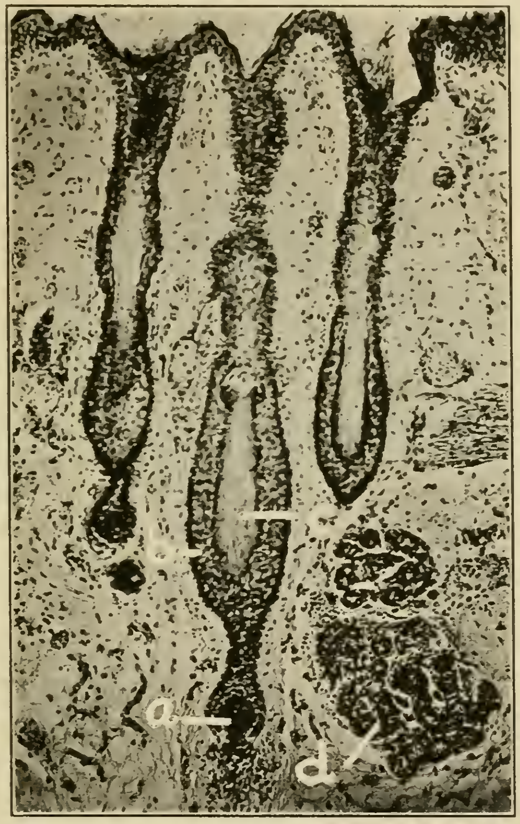


Fig. 243.—Longitudinal Section of Hair Follicles in the Scalp of a Fetus. *a*, Papilla; *b*, Epithelial root sheaths; *c*, shaft; *d*, sweat-gland. (Photograph. Obj. 16 mm., oc. 10 ×.)

Opening into the hair follicles are the **sebaceous glands.** This is usually upon the side toward which the hair leans, and here is also seen the muscle of the hair follicle, the **arrector pili** muscle. This is smooth muscle, and is attached above to the derma, just beneath the stratum Malpighii, and below to the hair bulb. When it contracts it causes the hair to "*stand on end.*" Arrector pili muscles are absent in hairs of the cheeks and lips and of the hairs of the eyelids (lashes) and of the nasal fossæ (vibrissæ).

The *blood-supply* of the hair is a special vessel that passes to the bulb and in the papilla, forms a tuft of capillaries and upon this the nourishment of the hair depends. The *venous* blood is returned to the general cutaneous plexus of the neighborhood.

Each hair receives *nerve fibers* for the papilla, follicle and arrector muscle. That for the follicle divides into branches that encircle the follicle and terminate between the epithelial cells of the root sheaths. That for the papilla forms a series of fine branches in the papillary connective tissue. The nerve fiber for the muscle is from the sympathetic system.

THE NAILS

The **nails** are peculiar appendages that serve for the protection of the ends of the fingers and toes, and consist of the **root** and the **nail-body.**

The **root** is the proximal end at which the organ grows. Here the epithelial cells are transformed into the hard substance that gives the nail its character. Along the sides, the nail is protected by an overhanging ledge of skin, which constitutes, at the root, the **nail-fold,** and at the sides, the **nail-wall.** The angle formed by the nail and wall is the **nail-groove.** The stratum corneum continues into the angle over the edge of the nail as the **eponychium.**

The **nail-body** consists of the **nail proper** and the **nail-bed** upon which the nail rests.

The **nail** *represents a greatly hypertrophied stratum lucidum.* The cells are flattened elements, in which the nuclei are indistinct, and the cytoplasm clear. At the proximal end is the root, and at this place alone the nail grows. It is marked by a white area, the **lunula.** Here the epithelial layer is so thick that the underlying capillaries are invisible according to some. According to others the color is due to the presence of keratohyalin granules in the cells. Still others believe that the light area is caused by the separation of the nail from the bed in this area. The cells also are said to contain keratohyalin granules. At the distal end, the nail projects as the **free edge,** which is produced by a forward growth due to the formation of new cells at the root area. The nail is derived from the cells of the stratum Malpighii of the root region. These new cells pass toward the surface, the cytoplasm becomes permeated with eleidin and the nucleus all but disappears. The result is the formation of a thick stratum lucidum that represents the nail. Nothing is added to the nail beyond the root area. From the root the nail is carried over the bed to the free edge at the rate of about 0.75 mm. per week.

The **nail bed** consists of the stratum Malpighii and the corium. The stratum Malpighii resembles that of the skin surface, and rests upon the papillated corium. That portion beneath the lunula is termed the **matrix.** The corium is composed of bundles of white fibrous and yellow elastic tissues that have a general longitudinal direction. Between the bundles are vertical fibers that pass from the periosteum toward the nail. The **papillæ** of the bed are not like those of the skin, but consist of long **ridges** that extend from the root to the end of the nail. They are small beneath the root, but increase in height as the free edge is approached, and end abruptly at that point. The nail bed is very vascular.

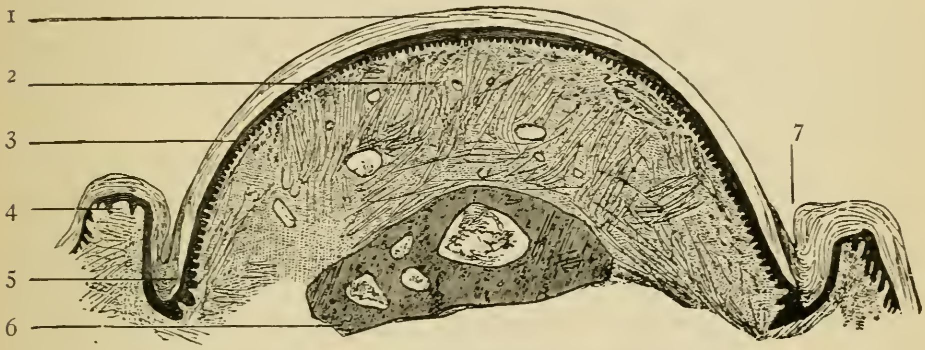


Fig. 244.—Cross-section of Nail.
1, Nail; 2, corium; 3, epithelium; 4, nail-wall; 5, nail-groove; 6, bone of phalanx; 7, eponychium.

The nails represent protective structures. In some of the lower animals they take the form of claws where they represent weapons of offense and defense. In still other forms they become markedly hypertrophied and extended so that the animal walks upon them, constituting their hoofs. In some animals, as the elephant, the nails are extremely sensitive.

THE GLANDS

The **glands** comprise the **sweat, sebaceous** and **mammary glands.**

The **sudoriferous** or **sweat-glands** are of the *coiled tubular* variety. Each consists of a *secretory portion*, 3 mm. long, three-fourths of which constitutes the coil that lies in the stratum reticulare, and an *excretory duct* that passes up through the derma and cuticle to open upon the surface.

The **secretory portion** consists of a *single layer of cuboidal* cells lining the tubule. These are separated from the *basement membrane* by a *layer of smooth muscle fibers.* This is wanting in the smallest sweat-glands and is best developed in those of the axilla, labia majora, root of the penis and circumanal region.

The cytoplasm is granular and may contain pigment granules and fat globules. There are said to be two varieties of cells present, one that is clear and the other that is dark and granular. During the period of rest the cells are taller and clear and intracellular and intercellular canaliculi are noted. The lumen of the tubule may be almost occluded. During the stage of secretory activity the secretion is poured into the lumen by way of the canaliculi, the cells are small and shrunken and the cytoplasm has a granular appearance. Delicate rods may be seen in the basal portions of the cells. The nucleus is usually quite distinct. The secretory tubule is coiled upon itself, and the various convolutions are separated from one another by interstitial tissue that corresponds to the tunica propria. The secretion is eliminated from the cells by inter- and intracellular capillaries.

The **duct** that leads from the secretory part to the surface has usually one-half the diameter of the secretory tubule, and is lined by *two layers* of cells that rest upon a *basement membrane* and *tunica propria* but muscle tissue is absent. In the epidermis its course is spiral, and *no separate wall is present*, the epithelial cells of the epidermis acting in this capacity. The diameter of this portion is greater than that of the corium. Its opening upon the surface is large and trumpet-shaped, visible to the naked eye and is called the **sweat-pore.**

These glands are generally distributed, *except on the margins* of the *lips, glans penis* and *inner surface of the prepuce.* They are most numerous in regions devoid of hairs as the palm, where they number about 370 per square centimeter; they are largest in the axilla. Upon the breast and abdomen there are about 155 per square centimeter while upon the limbs, neck and trunk there are about 60 to 80 per square centimeter.

The average diameter is 1 mm., but in the axillary region they may attain a size of 3 or 4 mm. comprising 30 to 40 mm. of coiled tube. In this region the secretory tubule *may be branched.* They acquire their large size at puberty, and have been termed *sexual odoriferous glands.* In the anal region the sweat-glands are mainly branched. Some of the large unbranched glands here are called *circumanal glands.*

The normal secretion is a thin watery fluid called *perspiration.* This represents an excretion and besides sodium chlorid contains a small amount of urea. These glands are, in a way, accessories to the kidneys and in certain diseases of the kidneys the sweat glands will excrete an increased quantity of urea. In addition to this function the sweat glands are important in maintaining an even body temperature. When the external temperature runs high the skin temperature tends to do the same but the sweat glands pour out their fluid and through the evaporation of this the temperature is held down. When the humidity and temperature are high, or during heavy exercise even in moderate weather the effort of these glands to maintain an even temperature of the body is seen in the great amount of perspiration formed. As the quantity formed is too great to be evaporated the excess runs off in streams.

The *ceruminous glands* of the eyelids, and of the external auditory canals and the circumanal glands are modified sweat glands. The secretion, however, is of a fatty nature but the general structure is the same. The glands of Moll of the eyelids and the circumanal glands are usually of the branched type.

The **sebaceous glands** are *racemose* structures. They vary in size from 0.2 to 2.2 mm. They are usually found in connection with the hair follicles; the largest hairs possess small glands, while the smallest hairs are appendages of the attached sebaceous glands. The largest glands are found on the nose where the ducts are visible to the naked eye. Each is surrounded by a capsule of white fibrous tissue that forms the supportive structure.

The **alveoli** are from 4 or 5 to 20 in number and are lined by cells that are a continuation of the cells of the stratum Malpighii, and which rests upon a *basement membrane* and *tunica propria*. The basal cells are small, while larger, rounded cells in various stages of fatty change completely fill the alveolus. Those in the center, where the lumen should be, are further advanced in changes than the basal cells. The entire cytoplasm becomes converted into oil, which constitutes the secretion, and is called **sebum**; the nucleus likewise degenerates. The sebum is semi-fluid and consists of fat and disintegrated cells. The death of the cell is necessary to the formation of this secretion. The transformed cell is immediately replaced by another. The excretory duct is lined by several layers of cells that do not take part in the secretory activity, and are derived from the outer root sheath of the hair follicle.

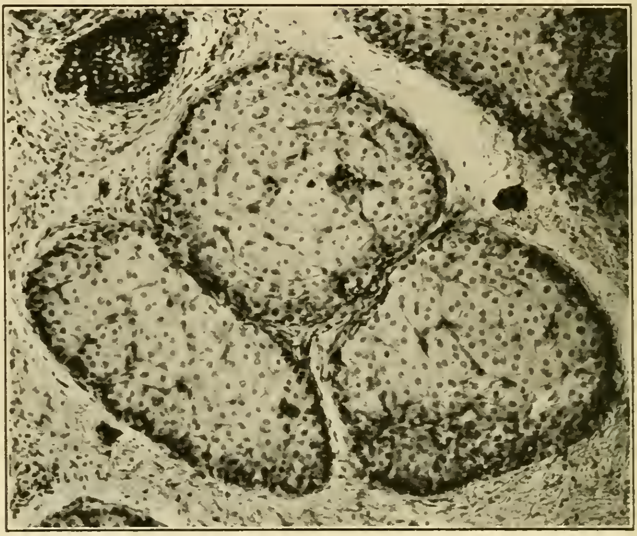


FIG. 245.—SECTION OF THREE ALVEOLI OF A SEBACEOUS GLAND SHOWING THEIR SOLID STRUCTURE. (Photograph. Obj. 16 mm., oc. 10 X.)

Sebaceous glands are found in some regions devoid of hairs, as in the *margins of the lips*, *glans penis*, *prepuce*, *glans clitoris* and *labia minora*. None are found in the palms and soles.

THE MAMMARY GLAND

The **mammary gland** is a *multiple alveolo-tubular* organ. According to some writers, it is a *modified sweat gland*, while others hold it to be a modified *sebaceous structure*. It is composed of from fifteen to twenty individual compound glands. Each of these possesses its own excretory duct, that has its own opening in the nipple. The entire organ is covered by skin. This gland grows somewhat in both sexes until puberty. Then in the male all but the main ducts atrophy.

Each gland consists of *lobes* and *lobules* separated and supported by white fibrous and adipose tissues. All of the individual glands are further bound together in the same manner. The ducts converge and end in the nipple, which forms a small projecting mass.

Each *lobule* consists of a number of *acini*, which are tubular or alveolar in structure. The number of these depends upon the state of activity. In the *gland of pregnancy*, the *acini* are very numerous, and are lined by *simple columnar*, or *cuboidal* cells, in which are accumulated the fat globules that form the important constituent of the milk. These cells rest upon a basement membrane, but in places are separated therefrom by peculiar elements called basket cells, which are compared to the smooth muscle tissue of the sweat glands. The *ducts* are lined by *simple columnar* cells that rest upon a *basement membrane*, outside of which circular bundles of white fibrous tissue are to be found. These ducts unite to form the main secretory duct of the individual glands; each main duct dilates to form a small **ampulla,** or **sinus lactiferous,** before the nipple is reached.

The *nonlactating gland* consists chiefly of white fibrous and adipose tissues, in which are seen a number of ducts, but few acini. The bulk of the organ consists of the fibrous and adipose tissues. When pregnancy occurs, the ducts divide and redivide, and the terminal portions dilate to form the acini. This increase in the glandular part causes the increase in the size of the organ, and the tingling sensation that occurs at that time.

After lactation has ceased, most of the acini undergo retrogression, atrophy, and disappear. Some of the ducts undergo the same change. As a result, the gland becomes somewhat smaller and flabby. In old age, or after the child-bearing period has passed, the glandular and ductular portions retrograde and disappear in the same manner, until in old age, they may be entirely absent. The glands are then represented by fibrous and adipose tissues.

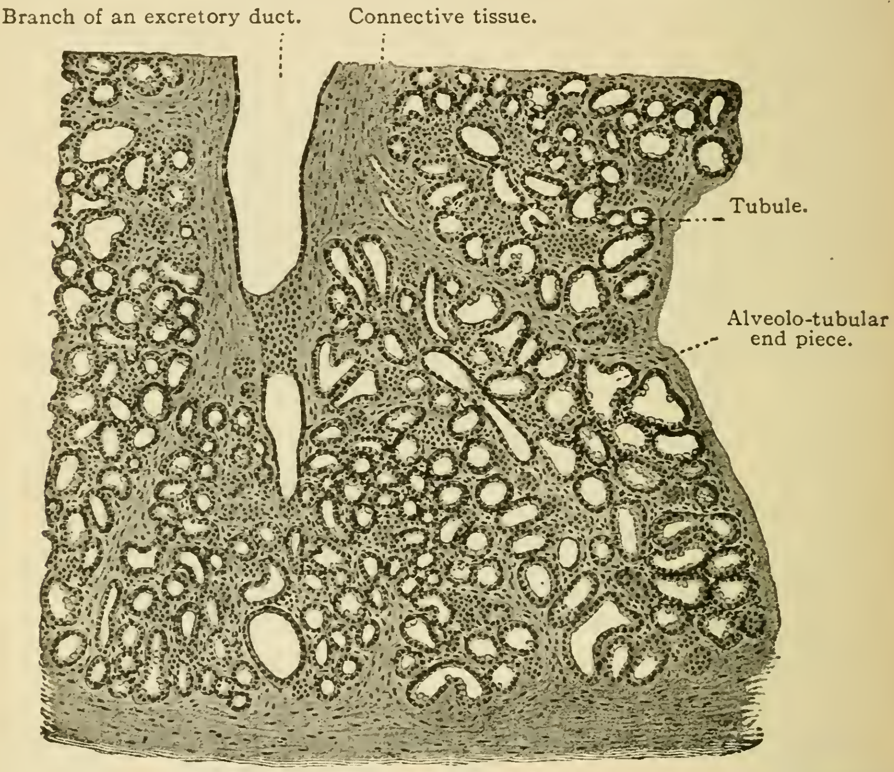


FIG. 246.—SECTION OF LACTATING HUMAN MAMMARY GLAND. (*Stöhr's Histology.*)

Milk consists of minute globules of fat, 0.1 to 0.5 mm. in diameter, surrounded by a thin layer of **casein.** This prevents them from coalescing. They are formed in the cytoplasm of the cells of the acini, but the cell, after discharging them, does not die, as formerly supposed. At first **colostrum** is present in the glands; this consists of fat and **colostrum corpuscles,** which are either degenerated gland cells, or leukocytes.

The **nipple,** or **mammila,** consists of an outer covering of pigmented skin, and within it the individual ducts are found. These are separated from one another by fibrous tissue and involuntary, non-striated muscle. The muscle tissue is arranged circularly and vertically, extending to the apex of the mammila. By its contraction, an erection is produced. Such tissue is called *false erectile tissue.* At the base of the nipple is a pigmented area called the **areola,** which contains a ring of branched tubular glands called the **glands of Montgomery.** These resemble the mammary gland and are regarded as transitional forms between the sweat and mammary glands. Occasionally rudimentary hairs are found in the areola.

In addition to the general blood-vessels, the various appendages have special supplies. From the *subpapillary arterial plexus,* branches pass to the hair follicles, to form one plexus beneath the hyalin membrane, and another in the papilla. The venous radicals formed, empty into *subpapillary plexus of veins.* Around the sebaceous and sweat glands, the subpapillary arterial plexus forms a close network of capillaries which form venous branches that empty into the subpapillary venous plexus.

The *blood-vessels* of the mammary gland converge toward it, and pass into the organ in the partitions between the lobules. From these vessels, branches extend into the lobules, and form close plexuses around the acini.

The appendages are supplied with *nerves* from both sympathetic and cerebrospinal systems. The hair follicles receive myelinated fibers that branch freely, and end in *spoon-shaped masses* upon the glassy membrane. The sweat glands are supplied with sympathetic fibers, that form a close network beneath the basement membrane, which they pierce, to end upon the gland cells. The mammary gland has both varieties of nerves. The sympathetic are the more numerous; these pass to the blood-vessels on the one hand, and to the acini on the other. In the latter, they form a plexus beneath the basement membrane, and from this plexus, branches end upon the gland cells. The nerve beginnings in the nipple are numerous.

The glands and hair follicles are surrounded by separate *lymphatic plexuses* that empty into the subcutaneous vessels. In the mammary gland, plexuses are found between the individual lobes, around the ampullæ and in the nipple. These empty into the axillary lymph nodes.

CHAPTER XVII

THE NERVE SYSTEM

The **nerve system** comprises two main divisions, the **central** and the **peripheral**. The central division consists of the *cerebrum, cerebellum, pons, oblongata* and *spinal cord;* the peripheral portion consists of the *cerebral* and *spinal nerves* and their connected *ganglia.* The central portions are surrounded by three membranes, the *dura*, the *arachnoid* and the *pia.*

The **dura** is a tough membrane composed of interlacing bundles of white fibrous and yellow elastic tissues that contain lymph spaces between them. Sensor nerves are numerous. Within the skull the dura comprises an outer part that is the periosteum of the bones of the skull and this is quite vascular; the inner portion is tougher and denser and less vascular and represents the real covering of the brain. It continues in between the two hemicerebri to form the *falx cerebri*, between the cerebrum and cerebellum it forms the *tentorium cerebelli;* other derivatives are the *falx cerebelli* and the *diaphragm sellæ.* It also forms the walls of the great venous sinuses of the skull and is continued upon the roots of the cerebral nerves for a short distance. At the foramen magnum the two layers become permanently and distinctly separated from each other, so that within the vertebral canal the dura hangs like a bag to the third division of the sacrum. Within this bag is the spinal cord. Within the spinal dura the bundles of fibers have chiefly a longitudinal direction.

Within the cranial cavity the internal surface of the dura is lined with endothelial cells and the membrane forms the outer boundary of the subdural lymph space. Within the vertebral canal both surfaces of the dura are covered with endothelial cells and the space between the dura and the bony canal is the *epidural lymph space.*

The **epidural lymph space** is not a simple cavity but is crossed by trabeculæ that connect the two layers of the dura. These trabeculæ are covered with endothelial cells. Within the vertebral canal where the two layers are well separated these trabeculæ form a series of large and extensive lymph spaces, while within the cranial cavity, where the layers are close together, these spaces are fewer and smaller. These spaces are in open communication and continuous with the lymph spaces around the vessels and nerves and these practically represent efferents of the epidural spaces.

The **subdural lymph space** is a clear-cut narrow cavity between the dura and the arachnoid. It is bounded by the endothelial cells that line the inner surface of the dura and cover the superficial layer of the arachnoid. As the membranes of the brain and spinal cord are continued upon the cerebral and spinal nerves for a short distance and then blend with the epineurium of these nerves this lymph space extends into the nerves and become continuous with the perineural lymph spaces that represent drainage channels for this space.

The **arachnoid** is a delicate, web-like membrane that is composed of loosely interwoven bundles of white fibrous tissue and a few elastic fibers; it is said to be devoid of vessels and nerves. It is closely applied to the pia but does not follow it into the fissures and sulci except in the case of the sagittal and lateral cerebral fissures. The peripheral surface of the arachnoid is covered with endothelial cells that are continuous with those lining the deep surface of the dura, but these two membrances are not connected to each other. The deep surface of the arachnoid is also covered by endothelial cells. From this surface numerous bands or trabeculæ pass to the pia so that instead of a clear-cut space between these two membranes a series of intercommunicating spaces is formed and these constitute the *subarachnoid lymph space.* The trabeculæ are covered with endothelial cells that are continuous with those covering the peripheral surface of the pia. This space does not communicate with the subdural space. The arachnoid forms a number of reddish-brown structures that project into the venous sinuses. These are the *Pacchionian bodies* (*granulationes arachnoideales*) and although they appear to lie within the sinuses they are, however, covered with a thin layer of dura. Through these the lymph of the subarachnoid space may reach the venous circulation. In certain regions the arachnoid and pia are separated more extensively forming spaces called the *cisternœ subarachnoideales.*

The **subarachnoid lymph space** is broader in the vertebral canal than in the skull. It communicates with the canal of the spinal cord and ventricles of the brain through the foramen in the dorsal wall of the fourth ventricle and through the lateral apertures of this ventricle. It has a capacity of about 5 cu. mm. and the lymph present constitutes the *cerebrospinal fluid.*

The **pia** is the *vascular membrane* of the brain and spinal cord as it contains all of the arterial vessels and some of the smaller venous channels. It is closely applied to the surface of the brain and spinal cord and enters into all of the fissures and sulci, more so in the cerebrum than in the cerebellum. It consists of two principal layers, an *outer* in which the fibers are longitudinal in the vertebral canal and the *inner* ones are circularly directed there. This layer formation is not so distinct in the pia of the cranial cavity as there is a tendency for the fibers to interlace. Between these two layers are the blood-vessels and the larger ones project into the subarachnoid space. The peripheral surface of the pia is covered with endothelial cells that represent a part of the boundary of the subarachnoid space and are continuous with those of the deep surface of the arachnoid. This surface is connected to the arachnoid by numerous trabeculæ, covered with endothelial cells. The deep surface of the pia is closely applied and firmly attached to the surface of the brain and spinal cord. This attachment is due to the delicate trabeculæ that extend into the nerve tissue accompanying the blood-vessels. In this deep layer are the smaller blood-vessels which enter the nerve substance from the outside.

Some *sensor* fibers are present in the pia but most of the nerves are of the sympathetic system and pass to the blood-vessels.

The nerve system is made up of two kinds of nerve tissue, **gray** and **white.** The gray substance is characterized by a grayish color. In the cerebrum and cerebellum it is generally arranged in layers that are visible only under the microscope. In the spinal cord, brain stem and ganglia the arrangement is different as will be pointed out when these structures are considered.

Gray nerve tissue consists of nerve cells and their processes, myelinated and amyelinated nerve fibers and neuroglia, the special supportive tissue of the nerve system. The **white substance** of the central nerve system consists chiefly of myelinated nerve fibers, neuroglia and a small amount of white fibrous connective tissue that accompanies the blood-vessels but this is not supportive to the neural elements. The **peripheral system** consists of some ganglia and of nerve fibers, the latter are supported mainly by white fibrous tissue that form the sheaths of the nerves. This portion of the nerve system has been considered under Nerve Tissues.

The nerve system consists of a series of inter-related and interconnected units that give a continuity of impulse from the central system to the periphery of the body and *vice versa*. These units are called *neurons*; each neuron consists of the nerve cell and its various processes. The nerve cell comprises the *cytom*, or cell body and the proximal portions of the dendritic and axonic processes. The distal portion of the axone and the distal portion of the principal dendrite, if it leaves the gray substance and becomes a nerve fiber as in the sensor system, constitute the *nerve fibers*. These fibers may be from a few millimeters to several feet in length.

Nerve cells vary in size and shape and may be *unipolar*, *bipolar* or *multipolar*, according to the number of processes. The main process is the *axone*, the others are the *dendrites*. If the axone leaves the gray substance the cells are classed as a cell of the *first type*, or *Deiter's cell*. If the axone remains within the gray substance the cell is of the *second type*, or *Golgi cell*.

The *neuroglia* consists of *glial cells* and *glial fibers*. The glial cells comprise *ependymal cells* and *astrocytes* of the *spider* and *mossy types*. For a detailed description of nerve cells, their processes, neuroglia and nerve fibers see Nerve Tissues.

In the cerebrum and cerebellum the gray substance is externally placed and constitutes the *cortex*; the white substance is internal, completely covered by the gray and is called the *medulla*. In the spinal cord the gray substance is collected into a characteristic mass internally and completely surrounded by the white substance. In the brain stem (oblongata, pons and midbrain) there is no special arrangement as the gray and white are more or less intermingled with each other.

THE SPINAL CORD

The **spinal cord** (*medulla spinalis*) the longest portion of the central nerve system and is that part within the vertebral column. It is suspended in the vertebral canal and is covered by the meninges of which the dura forms a bag. It is considerably smaller than the canal in diameter so that movements of the vertebræ do not injure it under normal conditions. It is somewhat cylindrical in shape and extends from the margin of the foramen magnum to the lower border of the first or upper border of the second lumbar vertebra. In the *male* it measures about 45 cm. and in the *female* about 43 cm. in length. Its weight, when stripped, is about 30 grams and with the nerve roots about 45 grams.

This portion of the nerve system is the longest. It is characterized by possessing the gray substance internally and the white substance externally. Its form varies in the different regions; in the cervical and lumbar areas, it is enlarged, and these enlargements are termed the **intumescentia cervicalis** and **lumbalis**, respectively. The cervical enlargement is at its maximum at the sixth cervical vertebra where its transverse dimension is 14 mm. and its dorsoventral measurement is 12 mm. The lumbar enlargement is greatest at the twelfth thoracic vertebra where it measures 13 mm. transversely and 11 mm. dorsoventrally. The outline in the *cervical* region is *oval*, in the *thoracic* region almost *circular*, and in the *lumbar* portion *oval*.

The increase in size at the enlargements is due to the added cells and fibers for the appendages. These enlargements vary in size according to the use of the appendages; in man, ourang and gibbon the cervical enlargement is the larger; in the kangaroo and ostrich the lumbar enlargement is the larger. In animals without appendages these areas are only slightly marked over the remainder of the spinal cord.

The cord ends in the neighborhood of the upper border of the second lumbar vertebra, and its termination is cone-shaped. This is called the **conus medullaris**. This includes the three lower sacral and the coccygeal segments. Its small size is due to the reduction of gray and white nerve tissues as by the time that this region has been reached most of the structures of the body have been supplied.

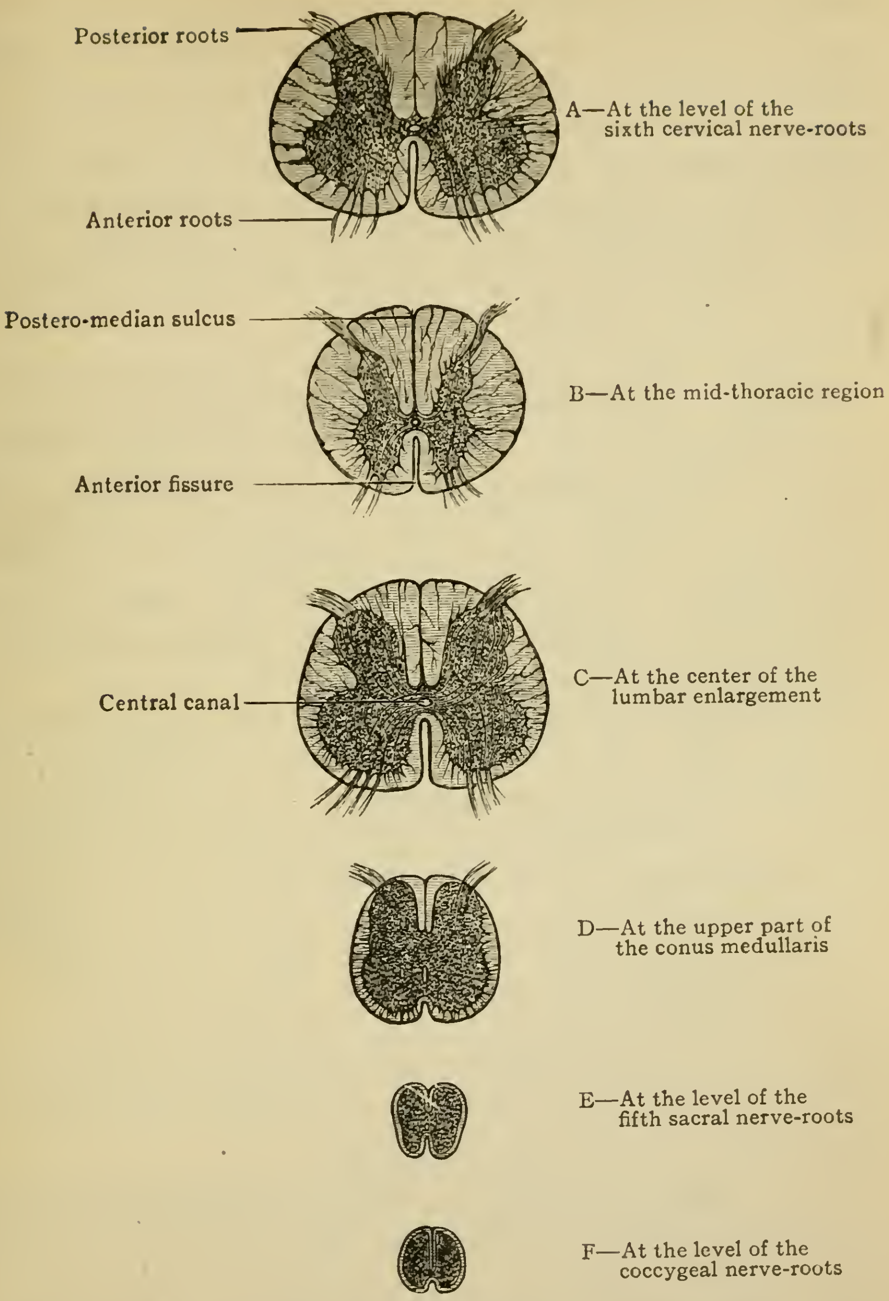

Posterior roots
Anterior roots
A—At the level of the sixth cervical nerve-roots
Postero-median sulcus
Anterior fissure
B—At the mid-thoracic region
Central canal
C—At the center of the lumbar enlargement
D—At the upper part of the conus medullaris
E—At the level of the fifth sacral nerve-roots
F—At the level of the coccygeal nerve-roots

Fig. 247.—Sections through Different Regions of the Spinal Cord. (*Morris after Schwalbe.*)

Owing to the fact that the cord is shorter than the vertebral canal, the lower lumbar, the sacral and coccygeal nerves pass down for varying distances before reaching their respective foramina. This produces a mass of fibers in the lower part of the canal called the **cauda equina.** In the center of the latter is a fibrous band that extends toward the end of the canal. It is the **filum terminale.** This consists chiefly of pia and is about 25 cm. in length. One-half lies within the dural sac and the remainder extends beyond it. Its peripheral end is attached to the coccyx.

The **cord**, upon section, consists of two hemispheres separated ventrally by the **ventral**, or **anterior median fissure**, in which is seen a process of the pia. Dorsally no fissure exists, but a **septum** is present. This is the **dorsal** or **posterior medium septum,** or **raphé.**

The gray substance of the cord is arranged in the form of a letter **H,** the two side bars constituting the **horns,** and the cross-bar the **gray, dorsal,** or **posterior commissure.** The **horns** are further subdivided into **ventral,** or **anterior,** and **dorsal,** or **posterior.** In the thoracic region a **lateral horn** is described.

The **ventral horns** are large and blunt, and do not extend to the periphery. In them are found collections of large, multipolar ganglion cells having a **motor** function. The axis cylinders of the cells pass out of the ventral portion of the cord as the **ventral root of the spinal nerve.** These cells average 60 to 120 microns, and are quite numerous. Each is surrounded by a distinct lymph space. They are collected into various groups which vary according to the region of the cord. The following are the most important.

1. The *ventromedian group* is found in nearly all segments of the spinal cord (except in the fifth lumbar and first sacral segments). This apparently represents the nuclei of origin of the nerve fibers that supply the long trunk muscles.

2. The *dorsomedian group* is found in the upper cervical, the thoracic and first lumbar segments, that is where no limb muscles are represented.

3, 4. The *ventrolateral* and *dorsolateral groups* are the largest and represent the nuclei or origin of the motor nerves of the muscles of the limbs. They are found in the cervical and lumbar enlargements and the upper sacral segments.

5. The *central group* is found chiefly in the lumbar and sacral segments.

6. The *intermediate*, or *lateral group* is a thin continuous column of cells in the thoracic and first two lumbar segments with recrudescences in the upper cervical and third and fourth sacral segments. This group represents the *splanchnic efferent fibers* (white *rami communicantes*) that pass from the cerebrospinal system to the sympathetic ganglia.

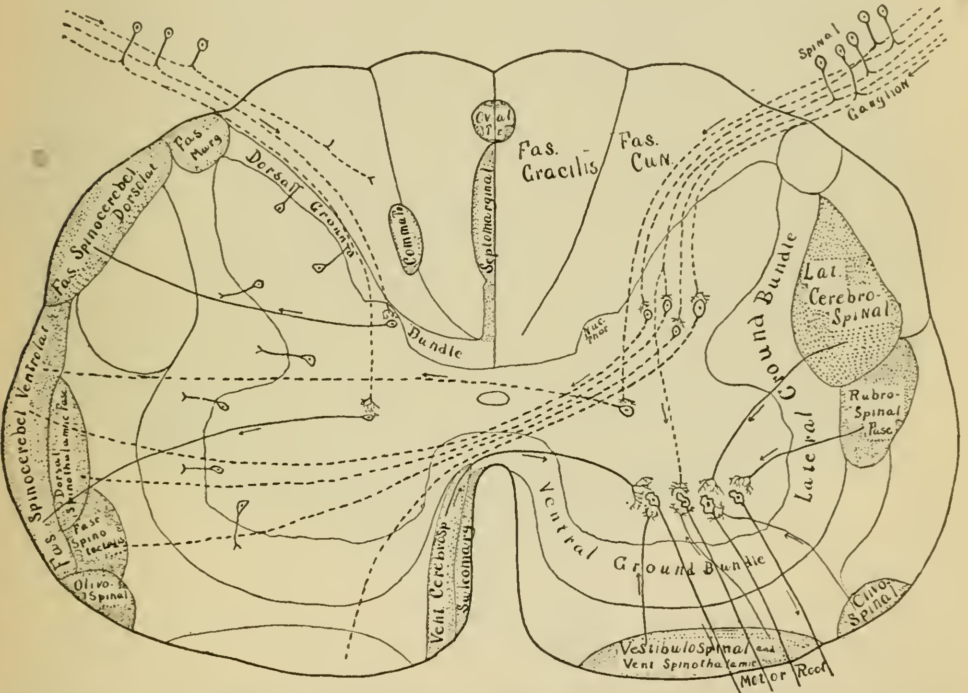

Fas. Marg
Fas. Spinocerebel Dorsolat
Dorsal Ground Bundle
Comma T.
Oval Tr.
Septomarginal
Fas. Gracilis
Fas. Cun.
Spinal Ganglion
Nuc. Thor
Spinocerebel Ventrolat
Dorsal Spinothalamic Fas
Fas. Spino tectalis
Olivo-Spinal
Vent. Cerebrosp
Sulcomarg
Ventral Ground Bundle
Lateral Ground Bundle
Lat. Cerebro-Spinal
Rubro-Spinal Fasc.
Olivo-Spinal
Vestibulospinal and Vent Spinothalamic
Motor Root

Fig. 248.—Diagram of the Various Tracts of the Spinal Cord and Their Origin or Termination. (*Radasch, "Manual of Anatomy."*)

Although many of the axones of the above cells form the nerve fibers of the ventral roots of the spinal nerves, the axones of other cells have a different course and function. Some of these axones as well as myelinate dendrites, pass to the medial and lateral sides of the ventral horns and form the ventral and lateral ground bundles. Upon entering these bundles the fibers branch T-like and the divisions pass up and down for one or two segments and then turn into the gray substance to end around the cells of the ventral horns of those segments. These fibers represent *intersegmental association fibers* and serve to connect several segments together for coördination of action of several muscles, or muscle groups. Other cells, especially those along the medial side of the ventral horns, send their axones and dendrites through the gray commissure to the other side of the cord as *commissural fibers*. The dendrites pass to the ventral horn cells of the same level and they do not leave the gray substance. The axones that cross enter the ground bundles of the opposite side, branch T-like, and the ascending and descending branches ultimately end in the gray substance a few segments above and below, terminating around the cells of the ventral horn.

The **dorsal,** or **posterior horns** are sharp and pointed, and usually extend to the edge of the cord. The cells here are small in number and size, averaging from 15 to 20 microns, and are scattered along the external margin. They comprise *marginal cells* that lie near the extremity of the dorsal horn and whose axis cylinders pass into the lateral columns after passing through the substantia gelatinosa; *spindle-shaped* cells are the smallest and neurits of these pass into the dorsal columns; *stellate* cells, the axis cylinders of which pass into the dorsal columns of Burdach.

Along the median edge of the dorsal horn, near its junction with the gray commissure, lies the only distinct group of cells that extends from the cervical to the mid-lumbar region. This is the **nucleus of Clark.** A similar collection, though less distinct, lies just ventral of Clark's column and extends through a greater part of the cord. This is the **nucleus of Stilling** and is represented in the oblongata by the *accessory cuneate nucleus*. Most of the axones of these cells pass to the dorsolateral columns of the same side forming the posterior spinocerebellar tract; the rest pass through the gray commissure to the opposite side, possibly to the white substance, constituting axones of commissural cells.

The **lateral horns** are most marked in the thoracic and upper cervical and third and fourth sacral regions. Each is formed, chiefly, by the *intermediate cell group*. The axones of these cells probably do not pass into the ventral roots but terminate within the cord at various levels of the same and opposite sides. They are probably closely connected with the sympathetic system and are vasomotor and sweat-gland nerves.

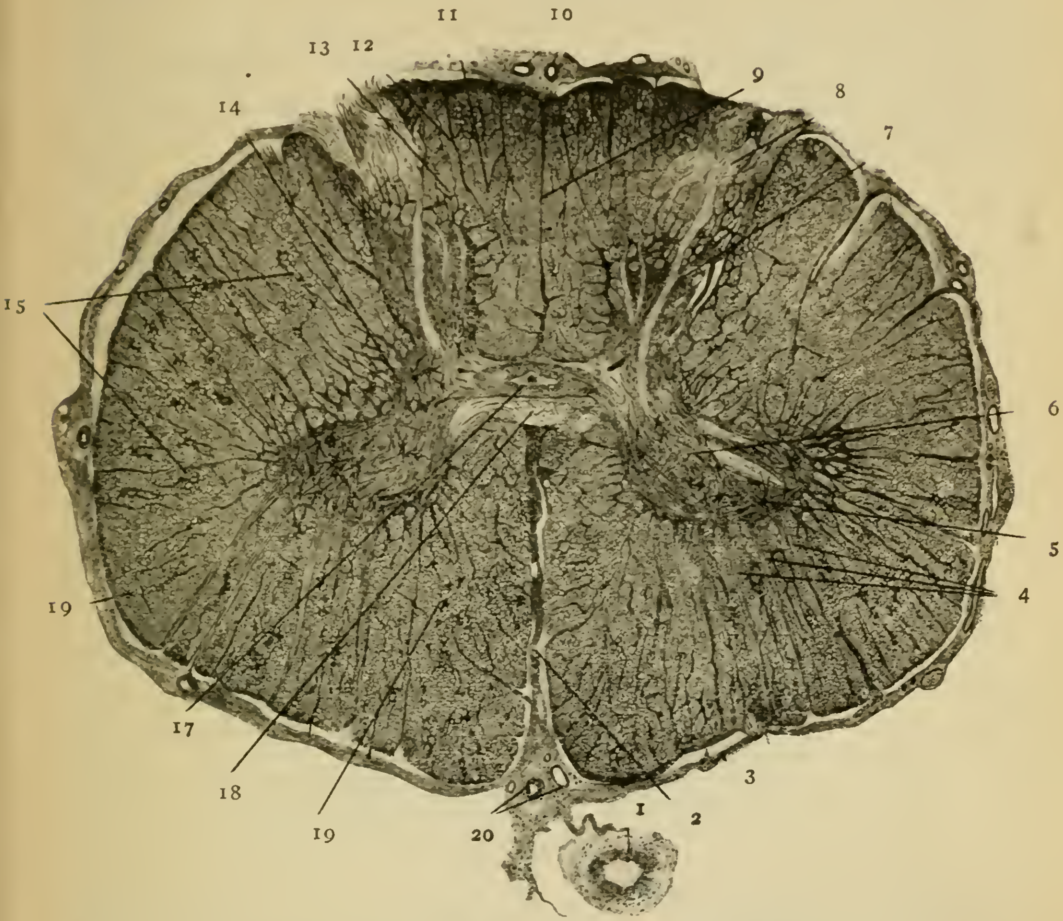


FIG. 249.—CROSS-SECTION OF HUMAN SPINAL CORD AT LOWER CERVICAL REGION. FROM DECAPITATED CRIMINAL. (*Dr. H. H. Cushing.*)

1, Ventral spinal artery; 2, pial process in ventral fissure; 3, dura; 4, nerve fibers from ventral horn (motor root fibers); 5, stellate cells of ventral horn; 6, ventral horn; 7, dorsal horn; 8, nerve fibers of dorsal horn (sensor root fibers); 9, dorsal septum; 10, dorsal spinal artery and vein (arteria et vena fissuræ posterioris); 11, fibers of the column of Goll; 12, tissue separating the columns of Goll and Burdach; 13, column of Burdach; 14, traces of the lateral horn; 15, fibers of the lateral columns; 17, central canal in the gray commissure; 18, ventral, or white commissure; 19, fibers of the ventral columns; 20, arteria et vena fissuræ anterioris.

In the dorsal horn is the **substantia gelatinosa Rolandi,** which consists of cells of the *second type* (*Golgi*).

The **gray commissure** consists of myelinated and amyelinated commissural fibers separated into **ventral** (smaller) and **dorsal** (larger) bands by the **central canal** of the cord. The ventral portion is called the **ventral, or anterior gray commissure,** while the other receives the name of **dorsal, or posterior gray commissure.** The whole is the **gray, or dorsal commissure,** in contradistinction to the **ventral, or white commissure.**

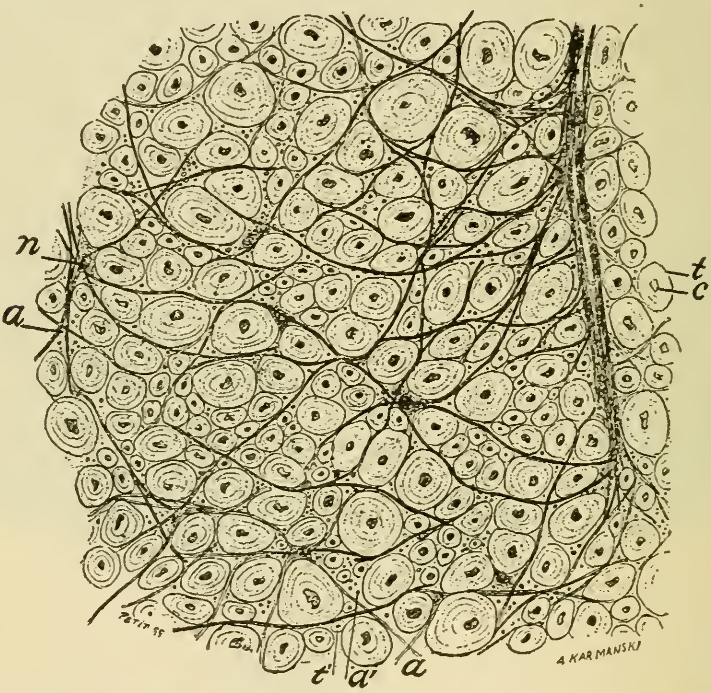


Fig. 250.—Cross-section of Spinal Cord showing Glial Fibers among the Nerve Fibers.

a, a, Glial fibers; *a′*, same cut across; *n*, body of glial cell; *t*, cross-section of a myelinated nerve fiber; *a*, axonal of same; *t′*, small (sensor?) nerve fiber. (*Schäfer after Ranvier.*)

The **canal** of the cord is the remains of the embryonal cavity within this portion of the nerve system. In childhood, it is lined by simple ciliated elements, the **endymal cells.** Above, it communicates with the fourth ventricle, and its form varies in the different portions of the cord. It becomes more or less obliterated with increasing age, partially by increased growth of the lining endymal cells and partially by the ingrowth of neuroglial processes, Besides the nerve cells, processes and fibers, the gray substance contains that peculiar supportive tissue found only in the nerve system, called **neuroglia.** This substance is ectodermal in origin.

Neuroglia consists of two varieties of cells, *ependymal* cells and *astrocytes*, which are **spider** and **mossy.** The **spider** cells are composed of thin, flat bodies from which extend long, slender processes. The **mossy** cells have short, heavy processes. In addition to these, there are some cells that possess large bodies and few processes. Fibers that, apparently, have no connection with any cell are seen passing over or under cell bodies. These processes all interlace to form a network for the support of the nerve cells and their processes. This substance is the **substantia spongiosa.** Around the central canal of the cord, the substantia spongiosa becomes more modified, and is called the **substantia gelatinosa centralis.** The network is much closer in this region. Around the dorsal horns, it forms a homogeneous, striated mass, in which a few nerve cells are found. This is the **substantia gelatinosa Rolandi, caput gliosum,** or **gliosa cornualis.**

The **white substance** consists of myelinated nerve fibers, connective tissue, and neuroglia. Spider cells are especially numerous here. The nerve fibers possess no neurilemma, and are grouped into columns. Ventrally, they are separated by the fissure, and dorsally, by the septum, into the hemispheres. Ventrally, they are connected by a band of white substance that lies between the bottom of the fissure and the gray commissure. This is the **white,** or **ventral (anterior)** commissure. The **motor** fibers are usually large, measuring 15 to 20 microns in diameter. The **sensor** are smaller.

The following columns are not found in any one section of the cord but represent all that are definitely bounded. Fig. 251 represents merely a diagrammatic section locating all the columns.

The **ventro-medium** columns that lie between the ventro-median fissure and the ventral roots of the spinal nerves; the **lateral,** that lie between the ventral and dorsal roots, and are subdivided into **ventro-lateral,** or those ventral to the transverse midline, and the **dorso-lateral,** or those behind the same line. The **dorso-median** columns lie between the septum and the dorsal roots of the spinal nerves, subdivided into **dorsomedian** and **dorsolateral.**

These areas are further subdivided into individual columns. In the **ventromedian** region, there are several groups: (1) the **direct pyramidal tract** (*fasc. cerebrospinalis anterior*). This is a narrow band of fibers that lies along the fissure, and represents the non-decussating fibers (10 to 15 per cent.) from the motor regions of the brain. The bundle is separated from the ventral fissure by the next tract. This tract usually disappears in the thoracic portion of the cord, though it may extend into the lumbar portion. These fibers decussate in the white commissure and end in the ventral horn of the opposite side. A *descending* tract.

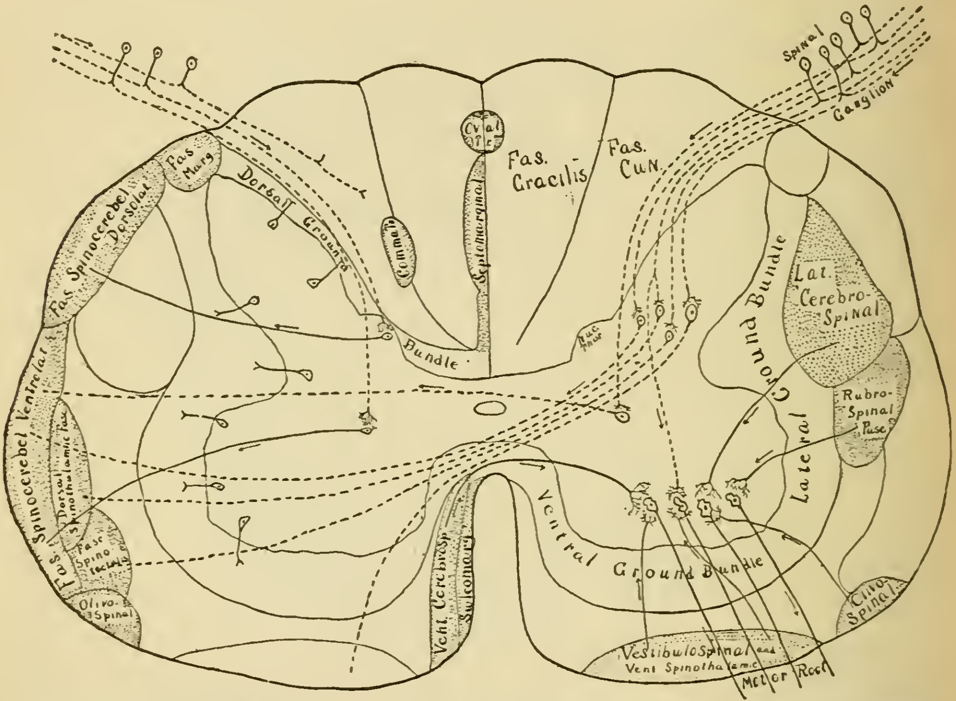

Spinal
Ganglion
Fas. Marg.
Fas. Spinocerebel. Dorsolat.
Dorsal Ground Bundle
Comma
Oval
Septomarginal
Fas. Gracilis
Fas. Cun.
Nuc.
Ground Bundle
Lat. Cerebro-Spinal
Rubro-Spinal Fasc.
Lateral
Fas. Spinocerebel Ventrolat.
Dorsal Spinothalamic Fas.
Fasc. Spino tectalis
Olivo-Spinal
Olivo-Spinal
Vent. Cerebrosp.
Sulcomarg.
Ventral Ground Bundle
Vestibulospinal and Vent Spinothalamic
Motor Root

Fig. 251.—Diagram of the Various Tracts of the Spinal Cord and Their Origin or Termination. (*Radasch, "Manual of Anatomy."*)

2. The **sulcomarginal tract** (*fasc. tectospinalis*) is found only in the cervical part of the cord and consists of decussated fibers from opposite quadrigemina and represents a *descending tract.* It lies next to the fissure, in the cervical segments of the spinal cord.

3. The **vestibulospinal tract** (*fasc. vestibulospinalis*) lies at ventral

surface of the cord and its fibers have been traced into the sacral portion of the cord. It consists of *descending* fibers, from the vestibular nucleus of the brain stem.

4. **Ventral ground bundle** (*fasc. anterior proprius*). This consists of fibers that arise in the cord and end in the cord, extending up and down for short distances in order to connect the various segments of the cord. These fibers are *associative* in function, and are *ascending* and *descending*.

5. The **ventral spinothalamic tract** (*fasc. spinothalamicus anterior*) lies in the intermediate zone of the ventral column and consists of axones of the cells of the dorsal horn, of the opposite side, that pass through the white commissure to form this tract. These fibers *ascend* and end in the thalamus. They convey touch and pressure impressions from the opposite side of the body.

In the **lateral** region of the cord are the following tracts:

1. **Superfical ventrolateral spinocerebellar** (**Gowers'**) lies in the superficial ventral portion of the lateral area. These fibers arise from the cells of the opposite side of the cord and pass through the white commissure and ventral horn to form this tract. These fibers ascend to the cerebellum through brachium conjunctivum and constitute *ascending fibers* that convey muscle-sense impressions, chiefly from opposite sides of the body. They are concerned with reflex actions.

2 **Olivospinal tract** (*fasc. olivospinalis*) lies just lateral to the ventral root and is found only in cervical and upper thoracic portions of the cord and represents *descending* fibers. This tract is probably related to the pyramidal tract.

3. **Direct spinocerebellar tract** (*fasc. spinocerebellaris posterior*) lies in the superficial dorsolateral area and consists of *ascending* fibers from the cells of the column of Clark. This tract is not found in the lower lumbar region of the cord. Its fibers terminate in the cerebellum reaching this organ through the inferior peduncles, (restiform body); they carry muscle-sense impressions and are concerned with reflex actions.

4. **Crossed pyramidal tract** (*fasc. cerebrospinalis posterior*) is in the dorsolateral region of the cord. It is composed of fibers that arise from the pyramidal cells of the cerebral cortex, decussate (85 to 90

per cent.) in the oblongata, and end in the ventral horns of the cord. In the cervical region it is internal to the direct cerebellar tract but in the thoracic area of the cord it comes partially to the surface, and in the lumbar region, where the direct cerebellar tract is absent, the crossed pyramidal tract lies entirely superficial. It is a *descending* tract.

5. **Lateral ground bundle** (*fasc. lateralis proprius*) lies against the gray substance and consists of *associative* fibers of both *descending* and *ascending* courses.

Lateral mixed tract occupies the remainder of the lateral columns and in it several tracts have been more or less completely outlined as follows:

6. The **ventral** and **dorsal spinothalamic tracts** (*fasciculi spinothalamicus anterior et posterior*) consist of fibers that arise from the cells of the dorsal horns of the opposite side; these pass through the white commissure to reach these tracts and pass up the cord to terminate in the thalamus. They are *ascending tracts*. The *ventral one* conveys impressions of touch and pressure and the *dorsal one* (scattered in Gowers' tract) conveys impressions of heat, cold and pain from the opposite side.

7. The **rubrospinal tract** (*fasc. rubrospinalis*) consists of axones that *descend* from the cells of the red nucleus of the midbrain to terminate about the cells of the ventral horn. It is a part of the indirect motor pathway.

8. The **tectospinal tract** (*fasc. tectospinalis*) consists of *descending* axones from the cells of the quadrigemina. These terminate about the cells of the ventral horn.

9. The **spinotectal tract** (*fasc. spinotectalis*) consists of *ascending* axones of the cells of the dorsal horn and they terminate about the cells of the corpora quadrigemina.

These last three tracts collectively are also termed the **fasciculus intermedius.**

In the **dorsal** region are seen the following tracts:

1. **Fasciculus gracilis** (**column of Goll**) lies adjacent to the dorsomedian septum and consists of *ascending* fibers that arise in the cells of the spinal ganglia (the axonic processes). These fibers end in the nucleus gracilis.

2. **Fasciculus cuneatus (column of Burdach)** lies peripheral to the preceding, and likewise consists of fibers (*ascending* axones derived from the cells of the spinal ganglia).

As the fibers of both bundles enter the cord they branch into a shorter descending and long ascending branches. The longer ones have been described. Most of the short ones soon end in the gray substance of the dorsal horns of the same side while the remainder cross to the opposite horn through the dorsal gray commissure.

3. The **comma tract of Schultze** (*fasc. interfascicularis*) occupies a position in the tract of Burdach at the boundary line with the tract of Goll. Its fibers are *descending*, and it consists of a group of the fibers mentioned in the preceding paragraph.

4. The **oval tract of Flechsig** (*fasc. cervicolumbalis*) is situated along the dorsal septum, is another group of the *descending* fibers.

5. The **marginal tract,** or **tract of Spitzka,** or **Lissauer,** is located along the dorsal root or among its fibers. It consists of some of the axones of cells of the spinal ganglia, which traverse not more than three of four segments and end around the cells in the gliosa cornualis. It is *sensor* in function and is probably concerned with transmission of pain sense.

6. The **septomarginal tract** (Bruce) is also *associative* in function and lies along the dorsal septum. Its fibers *ascend* and *descend*. Both of these tracts are most distinct in the lumbar region of the cord.

7. The **dorsal ground bundle** (*fasc. posterior proprius*) lies next to the gray substance of the dorsal horn and consists of short fibers that *ascend* and *descend;* they are associative in function.

The dorsal columns are the most complex of the spinal cord. It will simplify them to consider the course of the fibers as they enter the dorsal horns.

1. Most of these fibers form the fasciculi cuneatus and gracilis; these fibers divide into ascending and descending branches. The former branches are of variable length, some ending soon in the gray of the dorsal horn and some ending in the same way at higher levels Some of the ascending fibers of each spinal nerve continue to the oblongata and terminate around the cells of the nuclei cuneatus and gracilis. The descending fibers, that form the oval, comma and

septomarginal tracts, terminate around the cells of the gray substance of the dorsal horns.

2. Some of the fibers after entering the dorsal root zone course along the medial side of the gray of the dorsal horn and then enter it to terminate about the cells of the same level. They are concerned in reflex actions.

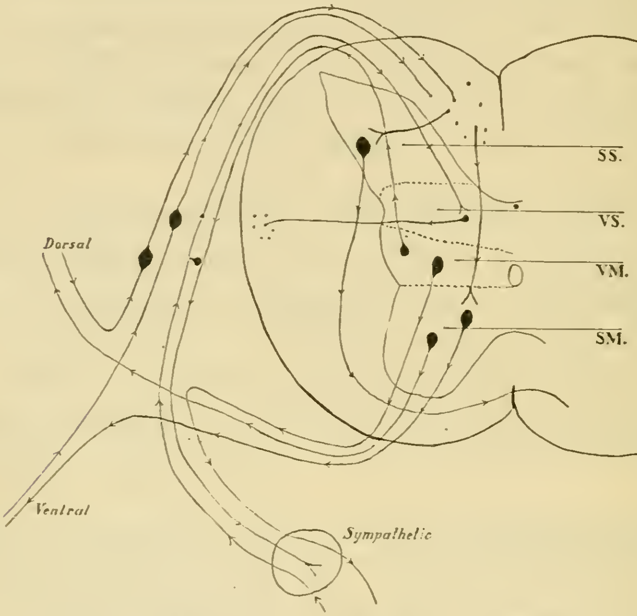


FIG. 252.—A DIAGRAM OF THE COMPONENT ELEMENTS OF THE SPINAL CORD AND ITS NERVE-ROOTS IN A TRUNK-SEGMENT ILLUSTRATING THE FOUR FUNCTIONAL DIVISIONS OF THE NERVE SYSTEM. (*After Johnston.*)

SS, Somatic sensor; VS, visceral sensor; VM, visceral motor; SM, somatic motor. The arrow heads indicate the directions of the impulses. *Note that visceral motor impulse passes out through the dorsal root.*

3. Some fibers of the dorsal roots enter into the formation of the marginal tract and terminate around the cells of the substantia gelatinosa and perhaps around other cells of the ventral and dorsal horns.

The *fiber tracts* consist of *extrinsic* and *intrinsic fibers*. The *extrinsic fibers* are: (*a*) those that arise outside of the spinal cord and traverse it or end in it; (*b*) fibers that arise in the cord and pass out of it. Under (*a*) are the tracts of Goll and Burdach, the crossed and direct pyramidal tracts, the vestibulospinal, olivospinal, some of the mixed lateral and marginal tracts. The direct cerebellar and Gowers' tracts and parts of the mixed lateral tracts come under (*b*).

The *intrinsic fibers* are those that arise and end in the spinal cord as the three ground bundles.

The gray substance of the cord can be subdivided *functionally* into the following categories: (1) **somato-motor**; (2) **viscero-motor**; (3) **viscero-sensor**; (4) **somato-sensor,** as shown in Fig. 252. The course of the various components of the nerve-roots is likewise shown.

The **spinal nerves** consist of **ventral, motor,** or **efferent,** and **dorsal, sensor,** or **afferent roots.** Before these unite to form the nerve, a mass of gray substance is seen *upon the dorsal root.* This is the **spinal ganglion.** The fibers of the **dorsal root** are derived from the cells that lie in the ganglia, and where they enter the cord, a distinct depression is noted. The fibers peripheral to the ganglion represent *myelinated dendrites* and those that enter the dorsal root of the spinal cord represent the *myelinated axones.* Upon examining Fig. 252 it will be seen that the dorsal root is *not purely sensor,* but also contains *viscero-motor fibers.* The **ventral root** is made up of fibers derived from the cells in the ventral horn, and where they emerge only a slight incurving of the surface is seen.

THE BRAIN

In order to consider the histology of the brain a brief and general description of its morphology will be first given.

The **brain,** or **encephalon** is the largest division of the central nerve system and is located in the cranial cavity. It is an ovoid mass of gray and white nerve tissue in which the white tissue predominates. Its *weight* is about 1400 grams in the male and 1200 grams in the female. At *birth* it weighs about 400 grams in the male and 380 grams in the female. By the end of the first year it has usually doubled its weight and by the end of the fourth or fifth years it is usually treble the weight at birth. It reaches its maximum weight about the eighteenth or twentieth years. The weight of the brain depends upon age, sex, race, intelligence, body weight and skull form. Its dimensions are frontooccipitally 16 to 17 cm., height (ventral to dorsal surfaces) 12.5 cm. and laterally 13 to 14 cm.

For convenience of description it is divided into *three divisions*, **cerebrum, cerebellum,** and **brain stem.** The parts will be described in order from the spinal cord end to the cerebral hemispheres.

The **brain stem** comprises the oblongata, pons and its tegmental part and the mid-brain.

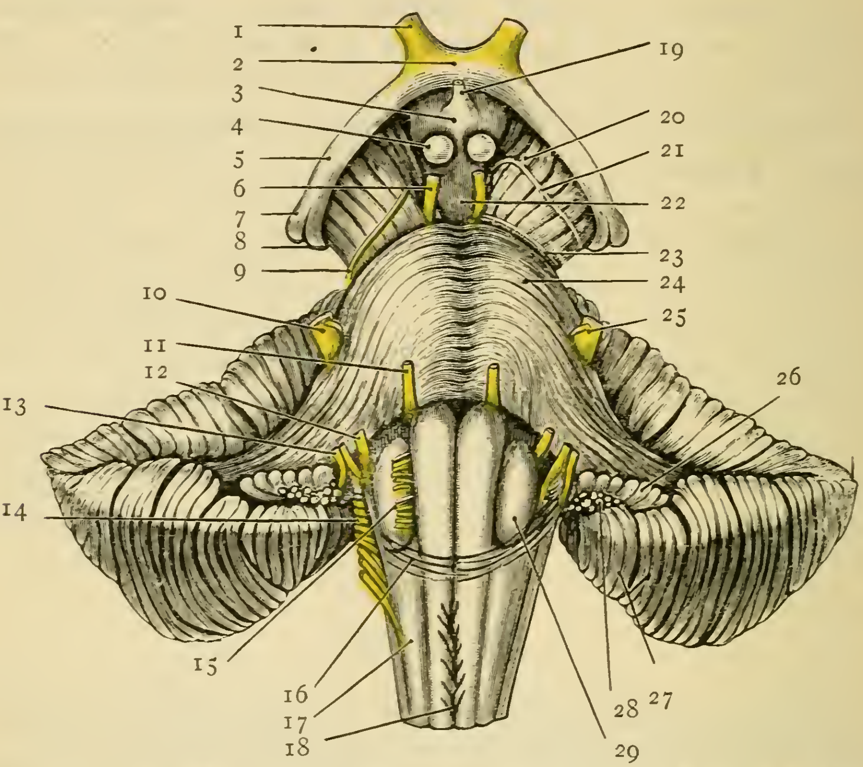


FIG. 253.—DIAGRAM OF THE VENTRAL SURFACES OF THE MID-BRAIN AND THE HIND-BRAIN. (*Morris.*)

1, Optic nerve; 2, optic chiasma; 3, tuber cinereum; 4, corpus albicans; 5, optic tract; 6, third nerve; 7, external geniculate body; 8, internal geniculate body; 9, fourth nerve; 10, fifth nerve. 11, sixth nerve; 12, seventh nerve; 13, eighth nerve; 14, ninth and tenth nerves; 15, twelfth nerve; 16, arcuate fibers; 17, lateral column; 18, decussation of pyramids; 19, infundibulum; 20, crus cerebri; 21, tractus peduncularis transversus; 22, posterior perforated space; 23, tænia pont s; 24, pons varolii; 25, fifth nerve; 26, flocculus; 27, biventral lobe; 28, cornucopia; 29, olivary body.

The **oblongata** (*myelencephalon*) measures about 12.5 cm. in length but the width varies; at the spinal cord extremity it is about 10 mm. in width and thickness while at the pontile end it measures about 17 to 18 mm. transversely and 15 mm. dorsoventrally. It represents a truncated cone that is flattened dorsoventrally. It is nearly vertical in direction and represents the connecting link between the spinal cord and the higher centers.

Upon its *ventral surface* is the *ventromedian groove* that is interrupted in part by the motor fibers that cross from one side to the other and form the *pyramidal decussation.* At each side of the groove is a tapering cylindrical mass called the *pyramid;* 90 per cent. of its fibers cross, as above mentioned, and the other 10 per cent. continue upon the same side for a variable distance into the spinal cord and then cross. The *lateral area* contains, near the pontile extremity, a small ovoid body about 12 mm. long called the *olive.* The remainder constitutes the *lateral column* which represents the continuation of some of the lateral tracts of the spinal cord (the dorsolateral cerebellar, Gowers' and lateral ground bundle). The caudal end of the olive is crossed by the *external* (*superficial*) *arcuate fibers.* In the lateral area are seen the nerve roots of some of the cerebral nerves (hypoglossal, spinal accessory, vagal and glossopharyngeal). The

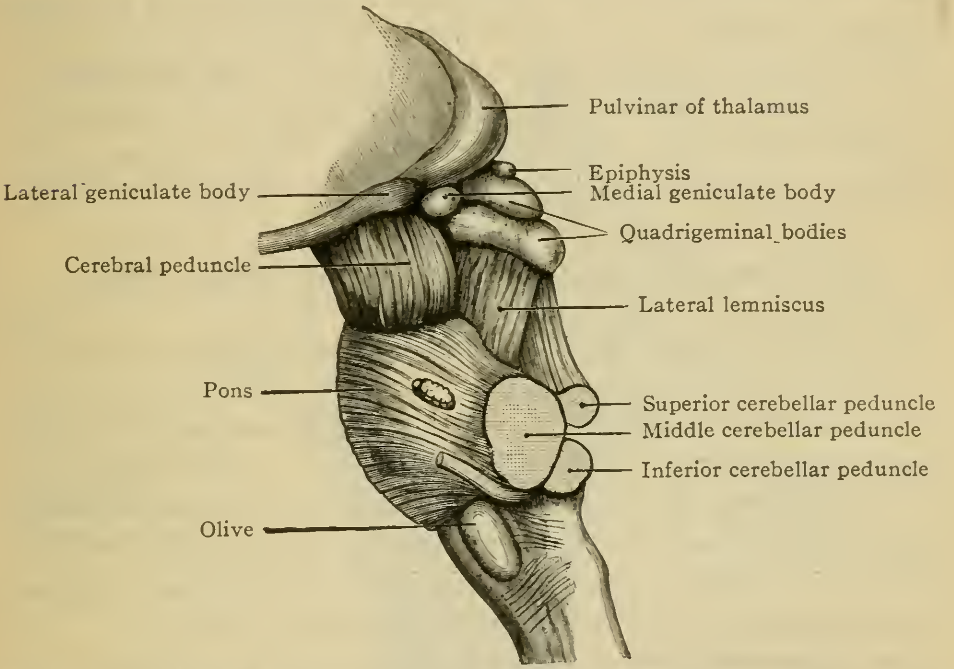

Pulvinar of thalamus
Epiphysis
Lateral geniculate body
Medial geniculate body
Quadrigeminal bodies
Cerebral peduncle
Lateral lemniscus
Pons
Superior cerebellar peduncle
Middle cerebellar peduncle
Inferior cerebellar peduncle
Olive

FIG. 254.—DIAGRAM OF LATERAL VIEW OF MESENCEPHALON AND ADJACENT STRUCTURES. (*Morris after Gegenbauer, modified.*)

dorsal area in its caudal portion, shows the *dorsomedian groove* which terminates above at the lower angle of the fourth ventricle. The *latter* is bounded upon each side by a club-shaped elevation, the *nucleus gracilis* lateral to which is the *nucleus cuneatus*. These two nuclei, on each side, are separated by a shallow groove, the *intermediate sulcus*. At the upper extremity of the nucleus is the *tuberculum rolandi,* an eminence that lies in the dorsolateral sulcus and causes that to fork at this point. The upper and median portion of the dorsal part of the oblongata is represented by the lower triangular portion of the fourth ventricle which is bounded upon each side by the *restiform bodies* that constitute the remainder of the dorsal area. These bodies consist of the fibers of the dorsolateral cerebellar tract (that enter them from the lateral columns of the oblongata and the superficial and deep arcuate fibers.

THE PONS AND TEGMENTAL PORTION OF THE PONS

The **pons** represents the broad band of fibers seen upon the ventral part of the middle portion of the brain stem. It measures about 2.5 cm. from above downward and the lateral boundaries are indicated by the roots of the two trigeminal nerves. From these roots on the transverse fibers of the pons constitute the *brachia pontis*. These brachia constitute the lateral areas of the pons and the fibers continue into each cerebellar hemisphere. In the pons area are seen the auditory, facial, abducent and trigeminal nerves.

The **tegemental part of the pons** cannot be seen ventrally. It really represents a continuation of the oblongata and has been well called the preoblongata. If a knife be passed frontally just dorsal to the pons mass and this be lifted off then the tegmental portion approximately, will be exposed. The dorsal surface of this part is the upper half, or triangle, of the fourth ventricle. This triangle is bounded laterally by the two overhanging, flattened masses of fibers that converge and form the apex of the triangle. These are the *brachia conjunctiva*. The so-called floor of the fourth ventricle is a layer of gray nerve tissue in which are some of the nuclei of origin and termination of cerebral nerves. The real roof, or dorsal wall is represented by two thin membranes called the *superior* and *inferior medullary veli*, which consist of a layer of ependymal cells reinforced by the pia and arachnoid. In the inferior velum there is an opening called the *foramen of Majendie* and at the lateral angles of the fourth ventricle are small openings in the roof called the *foramina of Luschka;* at the sides of the ventricle are the *lateral recesses* that communicate with the subarachnoid space of the ventral surface. By means of these openings the cerebrospinal fluid within the ventricular system can pass out of the brain into the subarachnoid space and *vice versa.*

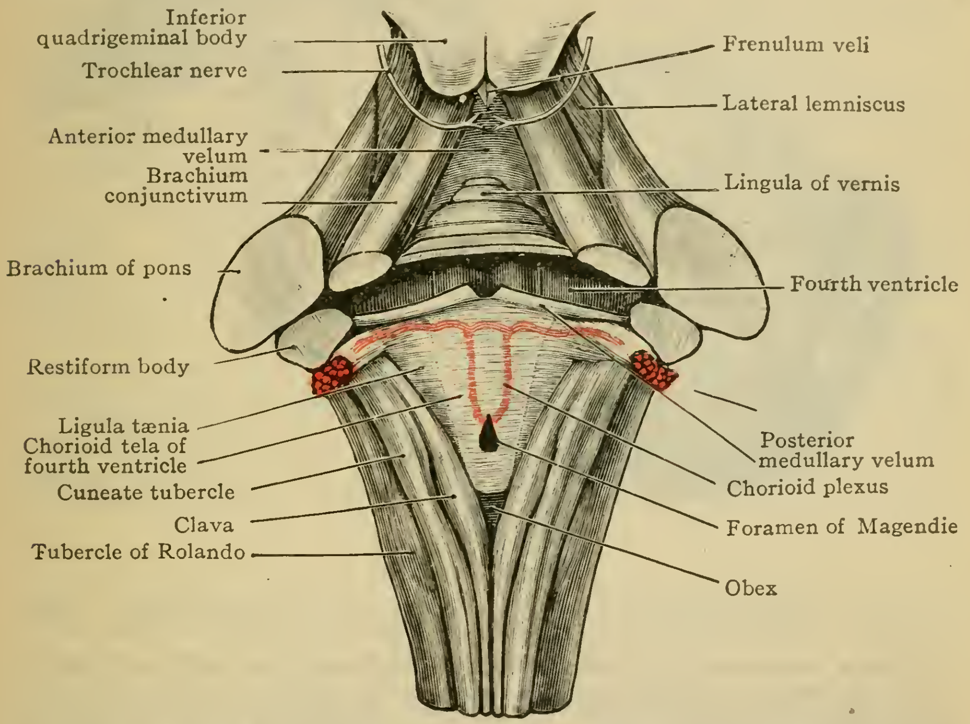

Inferior quadrigeminal body
Trochlear nerve
Anterior medullary velum
Brachium conjunctivum
Brachium of pons
Restiform body
Ligula tænia
Chorioid tela of fourth ventricle
Cuneate tubercle
Clava
Tubercle of Rolando
Frenulum veli
Lateral lemniscus
Lingula of vernis
Fourth ventricle
Posterior medullary velum
Chorioid plexus
Foramen of Magendie
Obex

Fig. 255.—Diagram of the Roof and Lateral Boundaries of the Fourth Ventricle. The Trochlear Nerve should be shown Emerging from the Lateral Boundary of the Frenulum Veli. (*Morris' Anatomy.*)

THE MID-BRAIN

The **mid-brain** (*mesencephalon*) is about 18 mm. in length and represents the upper portion of the brain stem. Upon its *ventral surface* are seen two very large, whitish masses, of a cylindrical form, that diverge from each other. These are the *crura cerebri* (*pedunculi cerebri*). Each *crus* looks like a rope-like mass of white fibers that starts at the upper border of the pons, but at a more dorsal level, and then passes upward (frontally) and laterally into the cerebrum. Between these diverging crura is a triangular area called the *interpeduncular space.* From this the oculomotor nerves emerge. At each lateral area of the mid-brain are seen a part of the crus, the *medial geniculate body* and the *superior* and *inferior brachia.* The *dorsal surface* of the mid-brain exhibits the *corpora quadrigemina,*

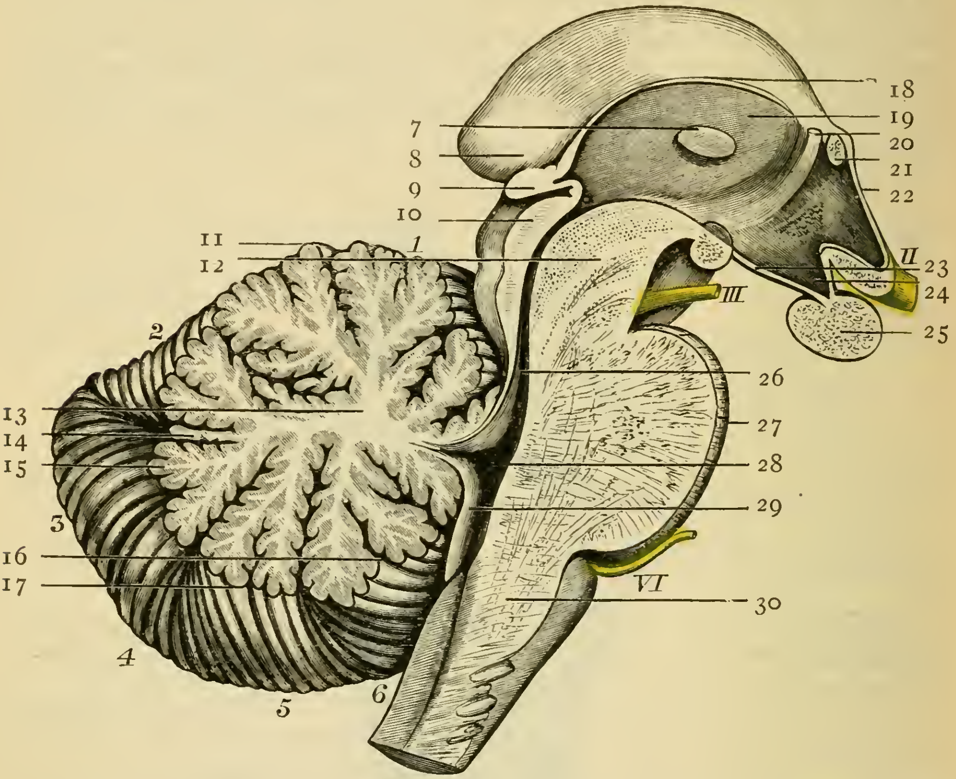


Fig. 256.—Median Section Through Cerebellum and Brain-stem. (*Allen Thompson, after Reichert.*)

1, Culmen monticuli; 2, superior semilunar lobe; 3, inferior semilunar lobe; 4, slender lobe; 5, biventral lobe; 6, tonsil; 7, massa intermedia; 8, thalamus; 9, epiphysis (pineal body); 10, corpora quadrigemina; 11, declive; 12, cerebral peduncle; 13, corpus medullare; 14, folium of vermis; 15, tuber of vermis; 16, uvula of vermis; 17, pyramid of vermis; 18, stria medullaris thalami; 19, third ventricle; 20, column of fornix; 21, anterior commissure; 22, lamina terminalis; 23, tuber cinereum; 24, recessus infundibuli; 25, hypophysis (pituitary body); 26, aquæductus cerebri (sylvii); 27, pons; 28, fourth ventricle; 29, tela chorioidea of fourth ventricle; 30, medulla oblongata.

or *colliculi.* These are four in number, *two superior* and *two inferior.* These are separated from one another by a longitudinal and a transverse furrow. The superior bodies are connected with eye muscle reflexes and the inferior are way-stations in the auditory pathway.

THE CEREBELLUM

The *cerebellum* lies in the posterior fossa of the skull and in man is completely covered by the occipital pole of the cerebrum. It weighs about 165 grams in the male and 155 grams in the female. It reaches its maximum weight between the twenty-fifth and thirty-fifth years. It represents an important coördinating center.

This structure consists of *two lateral lobes*, or *hemispheres*, and a *middle lobe* or the *vermis.* The lobes contain many fissures that have a transverse direction. The cerebellum is connected with the rest of the nerve system by *three pairs of peduncles inferior*, *middle* and *superior.* The *inferior ones* are the *restiform bodies* and serve to connect the cerebellum with the spinal cord, oblongata and cerebral nerve nuclei. The *middle ones*, the *brachia pontis*, are the largest and consist of fibers that mainly connect one cerebellar hemisphere with the other through the nuclei pontis. The *superior peduncles* are the *brachia conjunctiva* and serve to connect the cerebellar cortex with the mid-brain especially.

THE CEREBRUM

The **cerebrum** is the largest portion of the brain mass. It comprises the *cerebral hemispheres*, the *corpora striata*, the *olfactory tracts* and *bulbs* and these parts constitute the *telencephalon.* The *thalami*, *optic chiasm*, *hypophysis*, *optic tracts* and *lateral geniculate bodies* represent the *diencephalon.*

Ventrally are seen the *corpora albicantia*, or *mammillary bodies*, that are two, small whitish bodies one on each side of the interpeduncular space. They are way-stations in the olfactory pathway. The *tuber cinereum* is a hollow conical structure just in front of the preceding structures. To this the *hypophysis* is attached by a delicate stalk. This is a glandular structure that lies in the sella turcica of the sphenoid bone. The *optic chiasm* represents the convergence and decussation of the fibers of the optic nerves. These continue occipitally as two flattened bands called the *optic tracts.* The *lateral geniculate bodies* are small structures that represent way-stations in the optic pathway. *Laterally* and *dorsally* only the large *cerebral hemispheres* are to be seen. These constitute about six-sevenths of the brain and they are separated from each other in the midline by the *median longitudinal fissure.* Many fissures and sulci are seen upon the lateral and medial surfaces of each hemicerebrum. These tend to divide the surface into lobes and their subdivisions. The entire surface is made up of small folds called *convolutions.* At the bottom of the median longitudinal fissure is seen a broad band of white fibers that connects the two hemicerebri together. This is the *callosum* and it represents a commissure.

THE INTERNAL ANATOMY OF THE BRAIN [1]

As was noted in connection with the histology of the spinal cord the gray nerve tissue was arranged in the form of an H-shaped, fluted column with the white nerve tissue completely surrounding it. At the lower part of the oblongata this relation is somewhat the same with alternations due to the motor and sensor decussations. The canal of the spinal cord continues into the lower portion of the oblongata gradually approaching the dorsal surface until it is finally exposed; it then spreads and constitutes the shallow fourth ventricle. This is formed by the failure of nerve elements to develop in the dorsal wall of the neural tube in this region and as all of these elements and fibers are developed laterally and especially ventrally the ventricle is superficially placed. In the lower part of the oblongata the gray nerve tissue continues in close relation with the canal and as this canal becomes exposed the gray nerve tissue is found forming the so-called floor of the ventricle and constitutes the *ventricular gray substance.* It is as though the cord had been split open along the dorsomedian septum and the two halves spread apart and the canal exposed as a diamond shaped fossa (fourth ventricle). As a result of this change the motor cells are still ventrally placed but mainly near the midline; the originally dorsal sensor cells have been moved to the lateral region of the floor of the ventricle.

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[1] The internal anatomy of the brain stem and the description of the various pathways are taken from Radasch's "Manual of Anatomy" published by W. B. Saunders, Phila.

As the fourth ventricle passes frontally into the aqueduct it is as though the slit cord had again been restored to its original condition and the gray nerve tissue again surrounds the entire canal; the ventral or floor gray represents the seat of cerebral nerve nuclei (chiefly motor), while the dorsal gray is sensor (connected with the optic and auditory nerves). It is to be remembered that all of the nerve cells ventral to a line drawn transversely through the spinal canal are motor and those cells that are dorsal to this line are sensor.

The *motor cells* of the brain stem do not form continuous columns as in the spinal cord but are grouped into *three* interrupted *columns* constituting the nuclei of origin of the cerebral nerves. The *median* (*somatic*) *column* represents the nuclei of origin of the hypoglossal and abducent nerves. The *next column*, somewhat lateral to the preceding, is the *lateral somatic column* and consists of the accessory, part of the vagal and the facial and trigeminal nuclei. The nerve fibers go to the voluntary muscles of the tongue, larynx and pharynx. The *third*, or *splanchnic* (*visceromotor*) *column* is located farthest from the midline of the motor columns. This consists of the glossopharyngeal, facial and part of the vagal nuclei. The cells of these last nuclei are concerned with the movements of the smooth muscles of the viscera and their axones pass to sympathetic ganglia. These cells represent the intermedio-lateral group of the spinal cord.

The *sensor cells* likewise form groups of cells and not a continuous column. These groups are more isolated and lie farthest from the mid-line. They represent the nuclei of termination of the nerve of ordinary and special sense. The olivary, arcuate and pontile nuclei represent connecting links between the cerebellum and the remainder of the nerve system.

THE OBLONGATA

The histology of the oblongata will be considered in three cross-sections in ascending levels, as at the *motor* and *sensor decussations* and the *midolivary region.*

Motor Decussation.—In the pontile extremity of the oblongata the motor fibers all lie in a compact bundle in the ventral portion; here they form the pyramid. In the spinal cord end, however, about 90 per cent. of the fibers cross from one side to the other in bundles that interrupt the ventromedian fissure. These represent the *motor decussation*. Sections of this level will show these fibers sweeping dorsolaterally from one side of the fissure through the substance of the oblongata to the dorsolateral regions where they form the *crossed pyramidal tract* of the spinal cord. The remaining fibers continue down upon the same side as the *direct pyramidal tract* of the cervical and upper thoracic levels of the spinal cord. Ultimately they cross to the opposite side so that all of the fibers terminate upon the opposite side from which they originate in the cerebrum. The motor area of gray, represented by the ventral horn of the spinal cord, is thus cut into two portions: (*a*) the *isolated ventral mass* which is gradually pushed more laterally and is diminished in size at higher

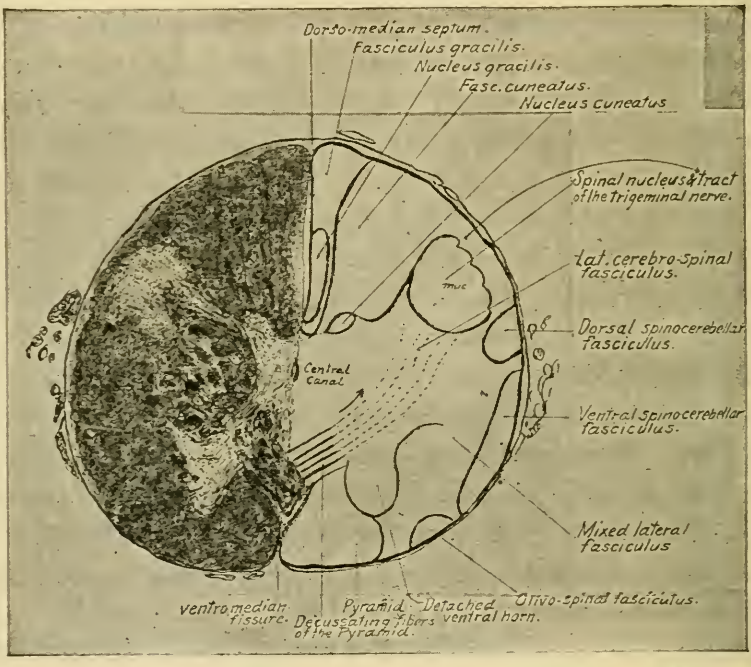

Dorso-median septum.
Fasciculus gracilis.
Nucleus gracilis.
Fasc. cuneatus.
Nucleus cuneatus
Spinal nucleus & tract of the trigeminal nerve.
lat. cerebro-spinal fasciculus.
nuc
Dorsal spinocerebellar fasciculus.
Central Canal
Ventral spinocerebellar fasciculus.
Mixed lateral fasciculus
ventromedian fissure.
Pyramid.
Decussating fibers of the Pyramid.
Detached ventral horn.
Olivo-spinal fasciculus.

Fig. 257.—Section of the Oblongata at the Level of the Motor Decusation (Weigert's Stain). The Right shows the Various Fasciculi and Nuclei in Outline. (*Radasch, "Manual of Anatomy."*)

levels; (*b*) the *basal part* along the canal, that represents the motor gray of the floor of the fourth ventricle in higher levels.

Dorsally a change is also noticeable upon the peripheral part of the dorsal horn; here the *substantia gelatinosa* has become greatly increased and forms a projecting mass upon the lateral surface of the oblongata called the *tuberculum cinereum.* The remainder of the dorsal gray also shows alterations. Near the dorsal median septum an elongated aggregation of cells makes its appearance among the fibers of the funiculus gracilis and this is the *nucleus gracilis.* In this nucleus the fibers of this fasciculus terminate. As the nucleus increases in size higher up it produces the elevation upon the dorsal surface called the *clava.* A little lateral to this nucleus, and upon the dorsal horn, another collection appears. This is the *nucleus cuneatus* and as it increases in size it produces the elevation of the same name upon the dorsal surface. In this latter nucleus the fibers of the fasciculus cuneatus terminate. In the lateral portion of the section lie the *lateral columns* and these fiber tracts pass uninterruptedly into the cerebellum, quadrigemina and thalamus. They comprise the several spinocerebellar, spinothalamic, spinotectal, rubrospinal and vestibulospinal and converse tracts.

The Sensor Decussation.—This lies just cephalad of the motor decussation but is not evidenced upon the surface of the oblongata. The ventral area of the section shows the *two pyramids*, each a compact bundle at the side of the ventromedian groove. Dorsal to these are seen first, a thin flat band the beginning *lemniscus*, or *fillet* (*lemniscus medialis*) and dorsal to this the *decussating sensor fibers.* These fibers arise from the cells of the nuclei gracilis and cuneatus and cross over to the opposite side of the oblongata. Between these decussating fibers and the side of the canal lie the wedge-shaped remains of the filaments of the hypoglossal nerve sweeping ventrally close to the pyramid. Lateral to these fibers are seen the remains of the isolated portion of the ventral horn somewhat smaller than in the preceding section. In the dorsal half of the section, the gray substance has a peculiar arrangement. Near the mid-line is the slender *nucleus gracilis* and just lateral to this the more massive *nucleus cuneatus* and then the *tuberculum cinereum.* Superficial to the tuberculum are seen some nerve fibers and cells that represent the *tractus spinalis nervi trigemini* and *nucleus tractus spinalis nerve trigemini.* At this level practically all of the fibers of the fasciculi gracilis and cuneatus have terminated.

Between this and the next section the nuclei cuneatus and gracilis disappear, several new nuclear masses, olivary nuclei, appear; in addition a great mass of nerve fibers, the *formatio reticularis* appears between the canal and the lemnisci and raises the canal to a more dorsal level until it is practically exposed and forms the fourth ventricle.

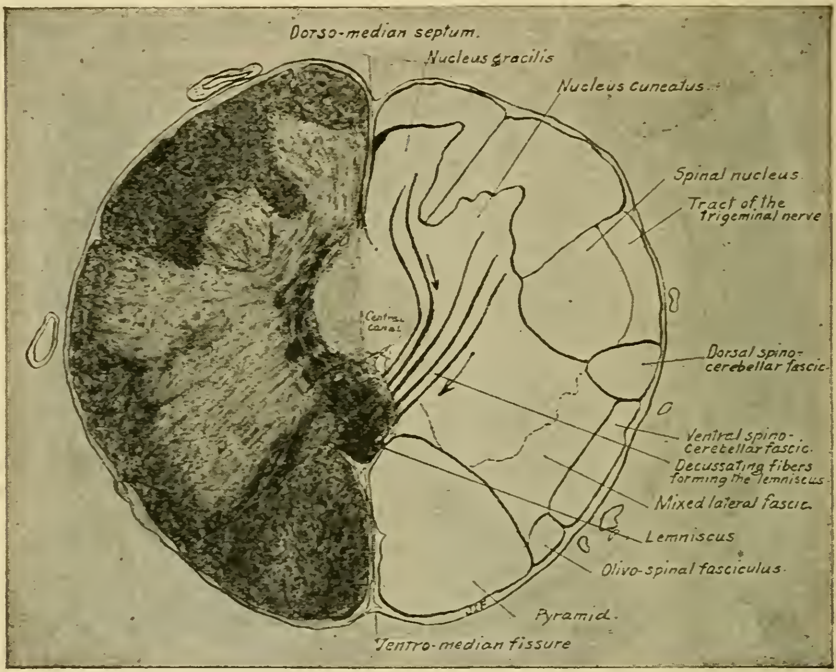

Dorso-median septum.
Nucleus gracilis
Nucleus cuneatus
Spinal nucleus
Tract of the trigeminal nerve
Central canal
Dorsal spino-cerebellar fascic.
Ventral spino-cerebellar fascic.
Decussating fibers forming the lemniscus
Mixed lateral fascic.
Lemniscus
Olivo-spinal fasciculus
Pyramid.
Ventro-median fissure

FIG. 258.—SECTION OF THE OBLONGATA AT THE LEVEL OF THE SENSOR DECUSSATION (WEIGERT'S STAIN). THE RIGHT HALF SHOWS THE VARIOUS FASCICULI AND NUCLEI IN OUTLINE. (*Radasch, "Manual of Anatomy."*)

Midolivary Level.—This section is markedly different. Upon each side of the ventromedian groove lies the large motor tract the *pyramids;* these are covered superficially by some gray nerve tissue, the *arcuate nucleus,* and some nerve fibers, the *superficial arcuate fibers.* Of these arcuate fibers some arise from the nuclei gracilis and cuneatus of the same side and pass to the cerebellum; others arise from the nuclei of the opposite side, decussate in the raphé, course ventrally and pass over the surface of the pyramid. Many of these fibers are interrupted in the arcuate nuclei and then pass to the cerebellum by way of the restiform bodies.

Just dorsal to the pyramids lie the *medial lemnisci* forming quite a thick bundle of longitudinally coursing fibers. They are separated from each other by the median raphé which extends dorsally to the ventricular gray substance. The raphé consists of a few nerve cells and fibers. Some of these fibers run longitudinally, others obliquely (the internal arcuate fibers) and still others course dorsoventrally (the external, or superficial arcuate fibers).

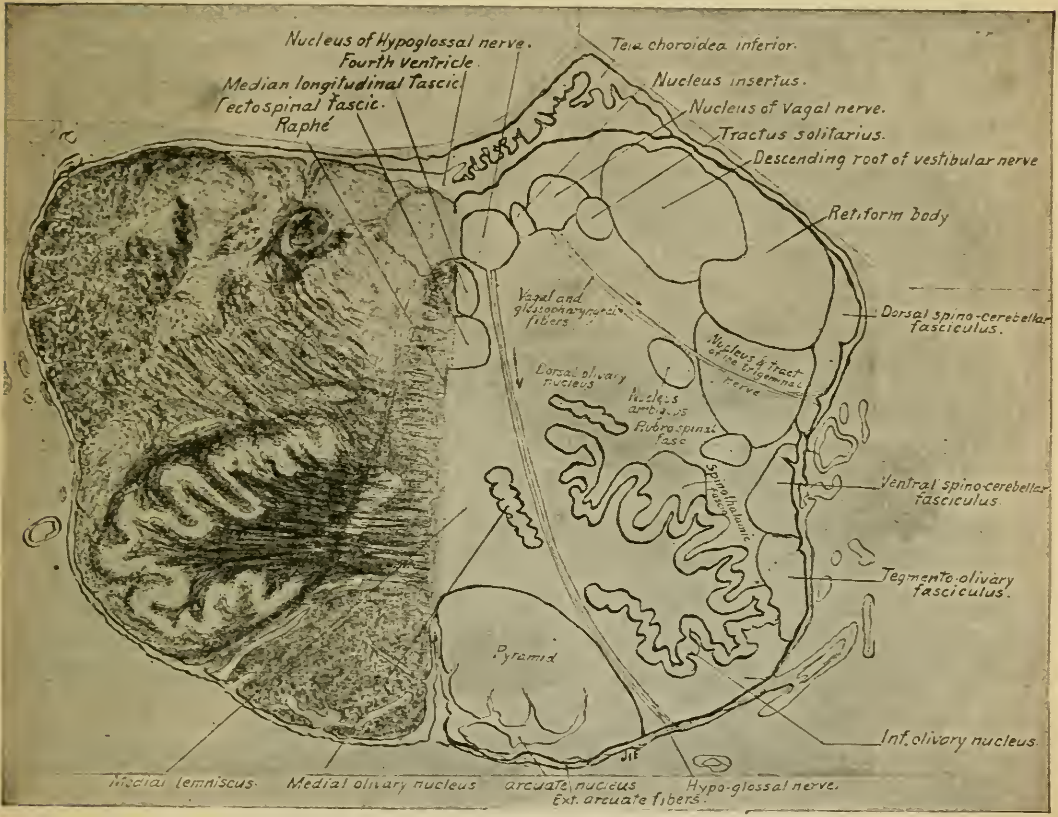

Nucleus of Hypoglossal nerve.
Fourth ventricle.
Median longitudinal Fascic.
Tectospinal fascic.
Raphé
Tela choroidea inferior.
Nucleus insertus.
Nucleus of Vagal nerve.
Tractus solitarius.
Descending root of vestibular nerve
Retiform body
Vagal and glossopharyngeal fibers
Dorsal spino-cerebellar fasciculus.
Nucleus & tract of the trigeminal nerve
Dorsal olivary nucleus
Nucleus ambiguus
Rubrospinal fasc
Spinothalamic fasc
Ventral spino-cerebellar fasciculus.
Tegmento-olivary fasciculus.
Pyramid
Inf. olivary nucleus.
Medial lemniscus.
Medial olivary nucleus
arcuate nucleus
Ext. arcuate fibers.
Hypo-glossal nerve.

Fig. 259.—Section of the Oblongata at the Level of the Midolivasry Region (Weigert's Stain). The Right Half shows the Variou Fasciculi, Nuclei and Nerves in Outline. (*Radasch, "Manual of Anatomy."*)

Dorsally between each lemnuscus and the floor of the fourth ventricle, on each side of the raphé, is seen the *formatio reticularis.*

This consists of bundles of nerve fibers that run longitudinally and transversely and some gray nerve tissue. The hypoglossal nerve divides this field into two parts. That which lies medial to the nerve is called the *formatio reticularis alba,* as it contains very few nerve cells; that lateral to the nerve is the *formatio reticularis grisea,* as it contains many nerve cells. The transverse fibers are chiefly internal (deep) arcuate and olivocerebellar while the longitudinal fibers are chiefly associative (short course) of the centers of respiration (nuclei of the facial, phrenic and vagal nerves) derived from the cells of the grisea. One especial group of longitudinal fibers just beneath the ventricular gray is called the *median longitudinal fasciculus.* This consists of longer association fibers that correspond to the ventral ground bundles of the spinal cord. They connect the various cerebral nerve nuclei together. The fibers just ventral to this bundle constitute the *tectospinal tract.*

Just dorsal to and a little to the side of the pyramid lies a crinkled mass of gray nerve tissue containing white fibers and surrounded by white fibers. This is the *inferior olivary nucleus* that produces the elevation upon the lateral surface of the oblongata called the *olive.* Its opening, called the *hilus*, is directed toward the raphé and of the fibers that leave and enter some pass to the olive of the opposite side while others pass to the cerebellum of the opposite side through the restiform body. Fibers of the converse course are also present. From the olive fibers also pass to the spinal cord and thalamus and *vice versa.* The dorsal and medial olivary nuclei are detached portions of the olive proper.

In the dorsal portion of this section is seen the *fourth ventricle.* The roof is thin and devoid of nerve tissue and constitutes the *tela choroidea inferior.* The floor consists of a layer of gray nerve tissue showing several aggregations of nerve cells, the nuclei of some of the cerebral nerves. On each side of the mid-line is the *nucleus of the hypoglossal nerve.* Just lateral to this lies a small group of cells, the *nucleus intercalatus* the function of which is not known. Lateral to this is one of the *nuclei of the vagal nerve.* That part of this nucleus nearest to the mid-line is *motor* (to the heart) and the lateral portion is *sensor.* In the lateral dorsal mass is seen a large group of fibers, the *descending root of the auditory nerve;* just beneath this are the *nucleus* and *fasciculus solitarius.* At the extreme dorsolateral portion is the *restiform body.* This structure contains the fibers of the direct spinocerebellar, cerebellospinal tracts of the spinal cord and the internal (deep) and external (superficial) arcuate fibers of the oblongata region. Beneath these structures is seen another *nucleus of the vagus* (the *nucleus ambiguus*) and fibers of the vagus. This nucleus probably represents the remains of the isolated portion of the ventral horn of lower levels. Near the side are seen the *nucleus* and *fibers of the spinal root of the trigeminal nerve.*

THE PONS AND PARS DORSALIS PONTIS

This portion practically represents a continuation of the oblongata with the pons added ventrally. Three sections, *lower*, *middle* and *upper* will be considered.

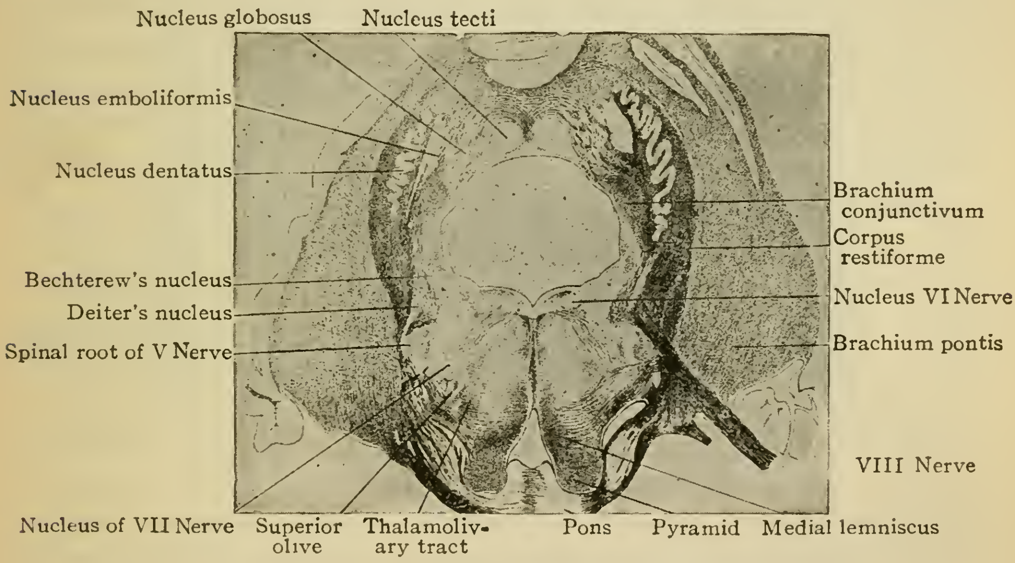

Nucleus globosus
Nucleus tecti
Nucleus emboliformis
Nucleus dentatus
Bechterew's nucleus
Deiter's nucleus
Spinal root of V Nerve
Brachium conjunctivum
Corpus restiforme
Nucleus VI Nerve
Brachium pontis
VIII Nerve
Nucleus of VII Nerve
Superior olive
Thalamolivary tract
Pons
Pyramid
Medial lemniscus

FIG. 260.—SECTION OF THE LOWER PART OF THE PONS REGION. (*Radasch, "Manual of Anatomy."*)

Lower Section.—The ventral portion of this section consists of a thick band of transversely coursing fibers (*pars basalis pontis*) and two large bundles of longitudinal fibers, the *pyramids*. The transverse fibers are more abundant in man than in any other animal and between the fibers are seen collections of nerve cells that are the *nuclei pontis.* Most of the fibers are ventral to the pyramids and they serve to connect the cerebellar hemispheres with each other. At the lateral boundaries of the pons these fibers collect into a compact bundle and enter the corresponding cerebellar hemisphere as the *brachium pontis.* Some of the pons fibers terminate around the cells of the nuclei pontis of the same side and others pass to the nuclei of the opposite side; new fibers then arise and go to the cerebellar hemispheres. Some of the cells of the nuclei pontis are also way-stations in the pathway of the cerebropontile fibers and new fibers arising here pass to the cerebellar hemispheres. The cerebropontile fibers have a longitudinal course.

In the area just dorsal to the pons fibers are the *pyramids.* Some of these longitudinal fibers terminate in the nuclei pontis and are the cerebropontile fibers. Dorsal to the pyramids are seen a variable number of *deeper transverse pontile fibers.* The arcuate nuclei and fibers of the oblongata are analogous to the pontile nuclei and fibers.

Dorsal to the pons lie the fibers of the *medial lemniscus* forming a rather compact bundle upon each side of the raphé. In higher levels these lemnisci diverge from the mid-line to make way for the trapezium.

The Pars Dorsalis Pontis.—The lemnisci separate the pons proper from the pars dorsalis (preoblongata). Dorsal to the outer side of the lemniscus is seen the *central tegmental tract* and the *superior olivary nucleus* connected with the fibers of the trapezium (acoustic fibers). Between the superior olivary nucleus and the formatio reticularis lies a bundle of fibers (*trapezial*) that form the *trapezium* of the next level. This portion also shows the *formatio reticularis* on each side of the raphé with the *median longitudinal fasciculus* in the dorsal area; between the formatio reticularis and the cavity of the ventricle is seen the *ventricular gray substance* in which certain cerebral nerve nuclei are seen.

Near the mid-line is seen the *nucleus incertus* (*Streeter*) that continues up to the aqueduct. To the side of this lies the *nucleus of the abducent nerve;* lateral to this the *principal vestibular nucleus* is noted and beneath the gray the *descending root of the vestibular nerve;* at the dorsal margin lies the upper end of the *restiform body.* Deeper ventral and over the superior olivary nucleus is the *nucleus* *of the facial nerve* while lateral thereto are some of the fibers of this nerve. Between the facial nerve and the restiform body are found the *substantia rolandi* and the *descending root of the trigeminal nerve.*

Trigeminal Nerve Level.—The ventral portion of this section shows the superficial and deep fibers of the pons embracing the two pyramids. At the sides the *brachia pontis* are present. At the junction of the pons with the tegmental portion the *medial lemnisci* have been pushed to the side and replaced by the *trapezium,* a set of transverse fibers (decussating) interspersed with nerve cells (the *trapezial nucleus*). These fibers arise from the ventral and some from the dorsal cochlear nuclei of the floor of the fourth ventricle and pass to the trapezium where some of the fibers terminate in the nucleus trapezoideus of the same or opposite side while some terminate in the olivary nuclei of the same or opposite side. The new fibers from the cells then cross to the opposite side (if the preceding have not) making the decussation complete; these fibers are then joined by new fibers from the cell of the opposite side and form the *lateral lemniscus.* The trapezium and lateral lemniscus are parts

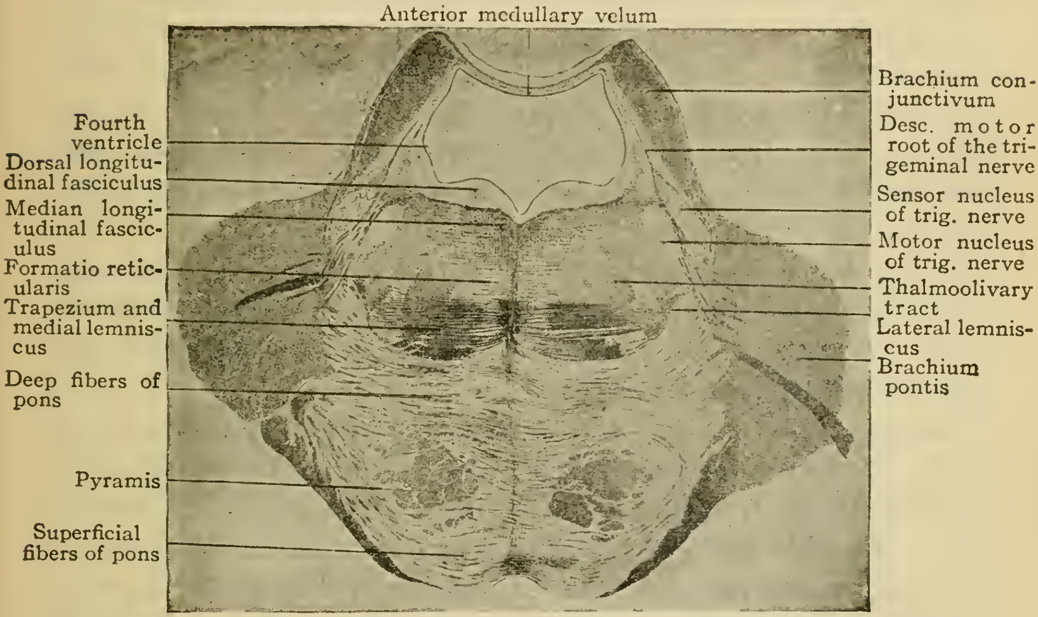

Anterior medullary velum
Fourth ventricle
Dorsal longitudinal fasciculus
Median longitudinal fasciculus
Formatio reticularis
Trapezium and medial lemniscus
Deep fibers of pons
Pyramis
Superficial fibers of pons
Brachium conjunctivum
Desc. motor root of the trigeminal nerve
Sensor nucleus of trig. nerve
Motor nucleus of trig. nerve
Thalmoolivary tract
Lateral lemniscus
Brachium pontis

FIG. 261.—SECTION OF THE PONS AT THE LEVEL OF THE ORIGIN OF THE TRIGEMINAL NERVE. (*Radasch, "Manual of Anatomy."*)

of the auditory pathway. Between the trapezium and the lateral surface of the section are seen the *superior olivary nucleus*, the *fibers of the motor root of the trigeminal nerve*, while more ventral are the *brachium pontis* and the *sensor root of the trigeminal nerve.* Near the surface lies the sensor root of the latter nerve.

Dorsal to the trapezium and in the mid-line is the raphé with the *formatio reticularis* forming a large field upon each side. Lateral to the formatio reticularis is the *motor nucleus of the trigeminal nerve* and upon the surface is the *superior cerebellar peduncle* (*brachium conjunctivum*) forming also the dorsal wall of this section. The peduncle is semilunar in shape, on section, and consists chiefly of fibers from the cells of the dentate nucleus of the cerebellum while the remainder are probably from the cerebellar cortex of the opposite side, decussating to reach this side. These fibers pass chiefly to the red nucleus of the mid-brain, but some continue to the thalamus.

In the dorsal portion of this section the fourth ventricle is seen becoming narrower and is roofed by the *valvula*, or *anterior medullary velum.* Beneath the ventricular gray and near the mid-line is the *median longitudinal fasciculus.*

The Upper Level.—A section through this part is smaller and more compact. In the ventral area the pyramids are separated into small bundles by the transverse pontile fibers. The *trigeminal nerve* is seen at the side of the field. The tegmentum shows changes. In the midline and dorsal to the pons fibers the decussating fibers of the brachia conjunctiva replace the trapezium and the somewhat flattened *medial lemniscus* is seen at the side of the section. The *formatio reticularis* lies just dorsal to the decussating fibers and laterally is the deeply placed brachium conjunctivum, covered by the flattened band-like *lateral lemniscus.* In the lateral lemniscus are some nerve cells that constitute the nucleus to this tract and probably represent a continuation of the superior olivary nucleus. In this nucleus some of the fibers (from the ventral cochlear nucleus) terminate and new ones arise from the cells of the nucleus and continue in this tract to end in the inferior quadrigeminum and medial geniculate body and possibly in the superior quadrigeminum. The dorsal median area of the formatio reticularis is occupied by the *median longitudinal fasciculus.* Dorsal to this area is the ventricular gray substance. In this section the fourth ventricle is small and entirely roofed over by the valvula which contains a little nerve tissue. At the lateral boundary of the ventricular gray is seen the *mesencephalic root of the trigeminal nerve.*

THE MID-BRAIN

Two sections, one through the *inferior* and the other through the *superior quadrigemina*, will be described here.

Inferior Quadrigeminal Level (Postgeminal).—This shows a great change over the preceding section. In the ventral area are seen the *two crura cerebri* separated by the *interpeduncular space.* Each *crus* consists of a ventral area, the *crusta* (*basis pedunculi*), containing only motor fibers in three groups: (*a*) the lateral one-fifth consists of fibers from the cortex of the temporal lobe to the nuclei pontis and they constitute the *temporopontile tract;* (*b*) the middle three-fifths consists of the fibers from the pyramidal cells of the motor area of the frontal lobe passing to the cerebral nerve nuclei and to the spinal cord, constituting the *pyramidal tract* previously mentioned; (*c*) the medial one-fifth consists of fibers from the cells of the frontal lobe passing to the nuclei pontis and these constitute the *frontopontile tract.* Dorsally the crus is bounded by a crescentic mass of pigmented gray substance called the *substantia nigra.* This separates the tegmentum from the crusta; the cells send their axones in various directions but their function is unknown. The substantia nigra extends throughout the mid-brain. The *tegmentum* consists of transverse and longitudinal fibers with collections of nerve cells here and there. It represents a continuation of the tegmental portion of the pons. In the midline is seen the raphé and at the side, above the substantia nigra, lies each *brachium conjunctivum* completing its decussation. Lateral to this is the *medial lemniscus.* Dorsal to the brachium, near the midline, is seen the *median longitudinal fasciculus*, while near the surface is located the *lateral lemniscus* covered by the inferior brachium. Dorsal to the raphé is the *aqueduct gray substance,* containing a small canal, the *iter*, or *aqueduct* (*aqueductus cerebri*). The gray substance surrounds the canal completely; in its floor and resting upon the median longitudinal fasciculus, is a collection of nerve cells, the *nucleus of the trochlear nerve.* At the side of the gray is the *mesencephalic root of the trigeminal nerve.* Dorsal to the aqueduct, on each side of the midline, is a rounded mass of gray nerve tissue covered by white fibers, the *inferior quadrigeminal body* (*colliculus inferior*). The nucleus of each body is separated from the aqueduct gray by the stratum lemnisci. This nucleus receives fibers from the lateral lemniscus. It represents a way-station in the auditory pathway and its cells send fibers to the thalamus.

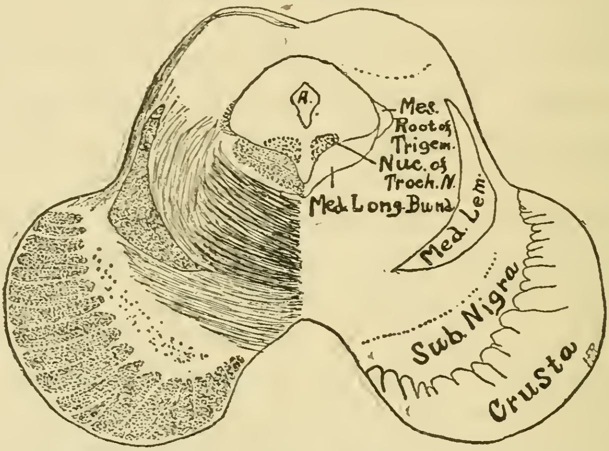


Fig. 262.—Transverse Section of the Mid-brain through the Inferior Quadrigeminal Bodies. (*Radasch, "Manual of Anatomy."*)

Superior Quadrigeminal Level (Pregeminal).—At this level the substantia nigra and crusta are practically unchanged. Medially, at the junction of the crusta with the tegmentum, is the *oculomotor sulcus* from which the oculomotor nerve emerges. Near the midline of the tegmentum there is a large reddish collection of nerve cells called the *red nucleus.* This is circular in outline and receives fibers from the cerebral cortex, corpus striatum and cerebellar cortex (through the brachium conjunctivum): most of the fibers of the latter structure terminate here. From its cells fibers pass to the thalamus and cerebral cortex and to the spinal cord as the rubrospinal tract. These latter fibers decussate almost immediately and pass down the opposite tegmentum.

At the side of the red nucleus lies the *medial lemniscus* and it is smaller as many of its fibers terminate in the superior quadrigeminal body; the remainder pass to the thalamus and are a part of the general sensor pathway. At the side of the lemniscus lies the *inferior brachium*. Between the two red nuclei lies the *fountain decussation*. These decussating fibers are derived from the superior quadrigeminal bodies and cells of the aqueduct gray, cross the midline and join the median longitudinal fasciculus and pass to the nuclei for the nerves of the eye muscles and to the spinal centers for movements of the head and neck.

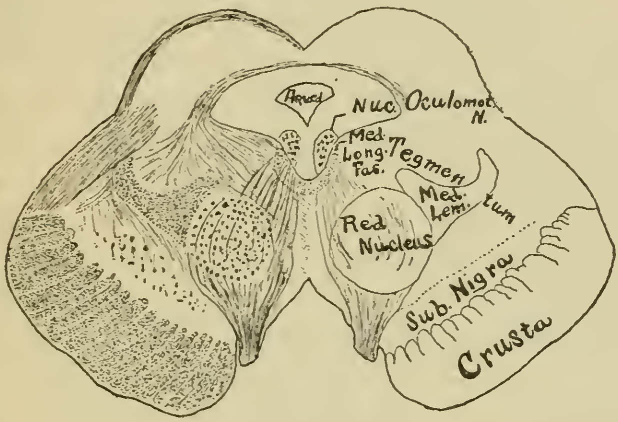


FIG. 263.—TRANSVERSE SECTION OF THE MID-BRAIN THROUGH THE SUPERIOR QUADRIGEMINAL BODIES. (*Radasch, "Manual of Anatomy."*)

The *median longitudinal fasciculus* occupies, relatively, the same position as in preceding sections. Its fibers are associative in function with regard to many cerebral and spinal nerve centers and it is analogous to the ventral ground bundles of the spinal cord. It especially connects the quadrigemina and the sensor cerebral nerve nuclei with the oculomotor, trochlear, abducent and facial nerves. A *special nucleus* is located in the floor of the third ventricle at its junction with the aqueduct. The fibers of the cells from this nucleus decussate immediately and cross to the opposite side through the *posterior commissure*.

In the dorsal part of the section are the aqueduct and the aqueduct gray which surrounds this canal. In the ventral part of the gray is the *nucleus for the oculomotor nerve*. Dorsal to the gray are the *two superior quadrigeminal bodies* (*colliculi superiores*). Each body consists of four layers of alternating white and gray nerve tissues. The white layers represent the fibers of the optic tract and some from the occipital cortex. Other fibers enter from the lateral and medial lemnisci representing a part of the acousticooptic reflex pathway.

THE CEREBELLUM

The **cerebellum,** or **little brain** has a characteristic gross appearance, when sectioned. Most of the gray substance is externally located while the white substance is internal. The gray constitutes the **cortex** and the white is the **medulla.** As the main fissures and sulci run transversely the cut edge of the cerebellum shows a peculiar arborescent appearance; this is called the *arbor vitæ cerebelli.* In the hemispheres the white tissue predominates while in the vermis the gray is more abundant. There are four buried masses of gray nerve tissue in the white and these are the *nuclei dentatus*, *fastigii*, *embolis* and *globosus*. The *nucleus dentatus* is the largest and most important and lies in the medulla of the lateral hemisphere. It is a crinkled mass of gray substance containing white fibers that enter and emerge by the *hilus*. This nucleus is important in the indirect motor pathway.

The **cortex** consists of three sharply marked layers, the (1) **molecular,** the (2) **ganglionic** and (3) **granule layers,** from without inward.

1. The **molecular layer** consists of a network of neuroglia, in which the dendritic branches of the cells of the lower layers are found. They are mostly those of the ganglionic cells These dendrites form a dense meshwork of fibrils the smaller ones of which show gemmules while the larger branches are smooth. In this network there are also some collaterals from the axones of the Purkinjé cells that seem to terminate in little knobs upon the cell bodies of neighboring Purkinjé cells. There are also a few small and large *multipolar cells* in the molecular layer. The *smaller cells* are more numerous in the superficial portion of the layer and are somewhat stellate in form with two to five slender dendrites. These divide into telodendrites that form part of the meshwork of the molecular

layer. The axones are short, run a horizontal course and they, with their collaterals, terminate in the outer part of this layer. The *large stellate cells* are more deeply placed. The dendrites are short and terminate among those of the Purkinjé cells. The axones are rather long, run a horizontal course and give off five or six collaterals that with the terminal portion of the axone pass to the second layer and each division forms a series of delicate branches around the body of a Purkinjé cell in the form of a basket, hence the name

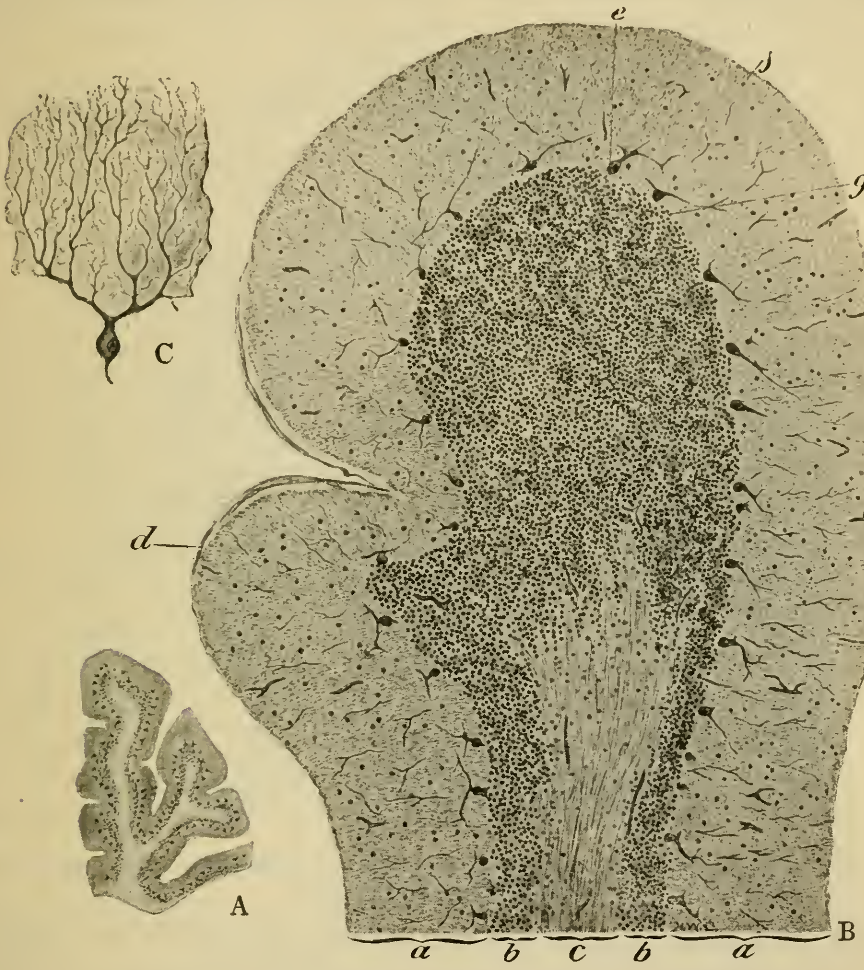


FIG. 264.—VERTICAL SECTION OF THE HUMAN CEREBELLUM.

A, Cerebellum, low power. B, Cerebellum highly magnified—*a*, molecular and ganglionic layers; *b*, granule layer; *c*, medulla; *d*, pia; *e*, cell of Purkinjé; *f*, cell of molecular layer; *g*, cells of the granule layer. C, Cell of Purkinjé.

basket cells. These are synapses and the basket cells are *association neurons.* The axones of the cells of the granule layer all terminate in the molecular layer contributing to the arborization there.

1. The **ganglionic layer,** or **layer of Purkinjé cells** is characteristic of the cerebellum. The bodies of these cells are very large, measuring 30 to 70 microns in diameter. The cytoplasm is fibrillar but contains no pigment granules. The nucleus is large, stains fairly well and the nucleolus is prominent and darkly staining. Two main processes extend from the body so these cells are of the bipolar type. The short heavy dendrite passes toward the molecular layer and quickly divides into two main divisions; these rapidly divide and

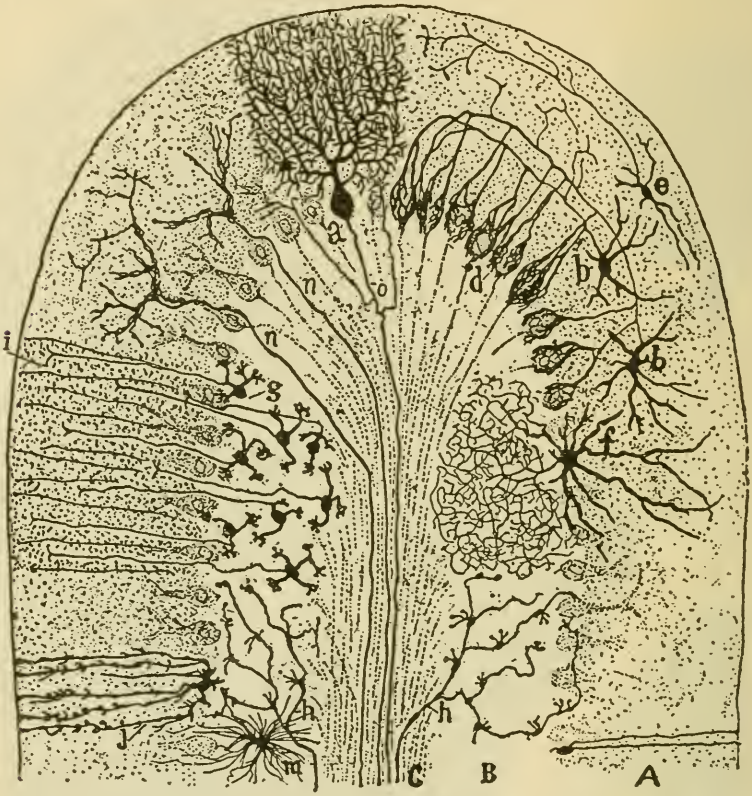


Fig. 265.—Cross-section of a Fold of the Cerebellum (Semidiagrammatic). (*From Bailey after Cajal.*)

A, Molecular layer; *B,* Granule layer; *C,* Medulla; *a,* Purkinjé cell; *b,* basket cells forming investment synapses of the Purkinjé cells at *d*; *e,* stellate cells; *f,* Golgi cell; *h,* granule cells; *i,* dendrites of granule cells; *h,* mossy fibers; *j, m,* glial cells; *n,* climbing fibers.

redivide forming a dense network of fibrils that extends straight upward and laterally to the surface of the molecular layer. This network is peculiar in that it is tall and broad but not thicker than the diameter of the cell body. The appearance is more that of a line of hedge than a tree. The axones pass at a right angle to the body and enter the granule layer, where they become myelinated, and continue into the medulla of which they form a considerable part. Numerous axonic collaterals are given off and these return to the molecular layer where they terminate around the bodies of neighboring Purkinjé cells. These cells are more numerous at the tops than at the bottoms of the convolutions.

Three kinds of axones terminate in relation with the cells of Purkinjé: (1) those of some of the granule cells that end in relation with its dendrites; (2) those of the basket cells that terminate in a network around the cell body; (3) those of the climbing fibers the branches of which wind around all of the dendritic branches except the terminal ones.

2. The **granule layer** consists of a broad zone of small and large granule, stellate cells and solitary cells. The *small granule cells* are the smallest nucleated elements in the body measuring as low as 4 microns in diameter. The axones of the granule cells are amyelinated and pass into the molecular layer where they branch T-like. These branches run parallel to the surface between the dendrites of the Purkinjé cells and are said to end in varicosities. The dendrites are short and remain in the granule layer where they terminate in fine branches around the **eosin bodies.** The latter are small masses of protoplasm, containing fine eosinophilic granules, and are supposed to represent synapses between the terminal teloneurites of the mossy fibers that come from the medulla and the telodendrites of the granule cells. The large number of small cells and the large number of darkly staining nuclei give this layer its granular appearance and name.

The *large stellate cells* are few in number and are found mainly near the Purkinjé cells. These are cells of the second type (Golgi); the axones are short, collaterals numerous and these terminate around the granule cells. The dendrites are numerous and pass to the molecular layer.

The *solitary cells* are some small, spindle-shaped cells the function of which is not known.

The granule layer is also thicker at the tops of the convolutions, diminishing as the base is reached.

In addition to the above structures and the neuroglia there are the *mossy* and *climbing fibers* in the cortex of the cerebellum. These represent the *afferent fibers* from the brain stem and spinal cord and they terminate in the cortex. The *mossy fibers* are very coarse fibers that branch in the medulla; these branches pass to different folds, or lamellæ. Within the granule layer the branches divide, become amyelinated and terminate in a number of short teleneurites that pass to the eosin bodies and end in relation with the axonic branches of the granule cells. These branches may present varicosities. The *climbing fibers* are also afferent fibers that enter the granule layer; they become amyelinated and branch profusely and near the body of the Purkinjé cells these branches wind about those of the dendrites like a vine. They are thus in relation with all

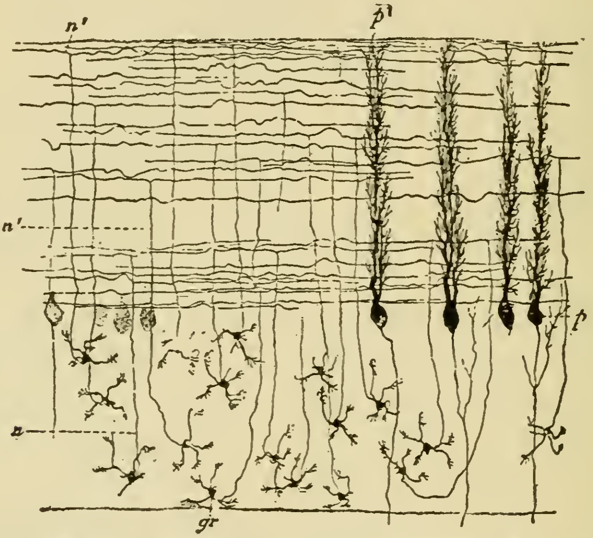


FIG. 266.—DIAGRAM OF A SECTION OF THE CEREBELLUM LENGTHWISE OF THE TRANSVERSE CONVOLUTIONS. GOLGI'S METHOD. (*Koelliker.*)

gr. Cells of the granular stratum; *n*, their neuraxons in the granular layer and *n'*, in the gray stratum; *p*, *p'*, Purkinjé cells. (*From Bailey's "Histology."*)

but the terminal telodendrites of the Purkinjé cells. These fibers come from the pons.

The **medulla** consists of myelinated nerve fibers supported by neuroglia and some white fibrous connective tissue. The fibers are *centrifugal* and *centripetal.* The *former* represent the myelinated axones of the Purkinjé cells that pass from the cortex to the various nuclei of the cerebellum but not out of the cerebellum directly. The *centripetal* fibers are those that come into the cerebellum from outside sources and represent the fibers from the spinal cord and brain stem; these are the mossy and climbing fibers mentioned as terminating in the cortex.

The **glial tissue** is considerable in quantity in both cortex and medulla. The glial fibers form a meshwork for the support of the nerve cells and processes and the nerve fibers. In the cortex the mossy cells predominate while the medulla contains only the spider type. The extreme superficial portion of the molecular layer possesses no nerve cells and very few processes and here the neuroglia forms a rather dense *marginal layer.*

THE CEREBRUM

Besides the **cerebrum,** there are other masses of nerve tissue to be considered here. These are the **olfactory lobes,** the **pituitary** and **pineal bodies.**

The **gray substance,** or **cortex** of the **cerebrum,** is divided into layers that are not sharply limited from one another. In some regions, *five* can be made out, in others *three,* while *four* form the average number. In the occipital lobes eight layers can be demonstrated. The **cortex** is made irregular by the formation of fissures and convolutions. The latter consist of a central mass of white substance, **medulla,** covered by the gray substance, or **cortex.**

The **cortical layers of the motor area** are, from without inward: (1) *molecular,* (2) *outer polymorphous,* (3) *small pyramidal,* (4) *large pyramidal,* (5) *inner polymorphous layers.*

1. The **molecular layer** consists chiefly of neuroglia and cell processes; the latter are chiefly dendrites derived from the deeper layers. The neuroglia forms a meshwork within which these

dendrites form networks tangential with the surface so that this layer is sometimes called the layer of *tangential fibers*. The cellular elements are few in number and of the second type and represent

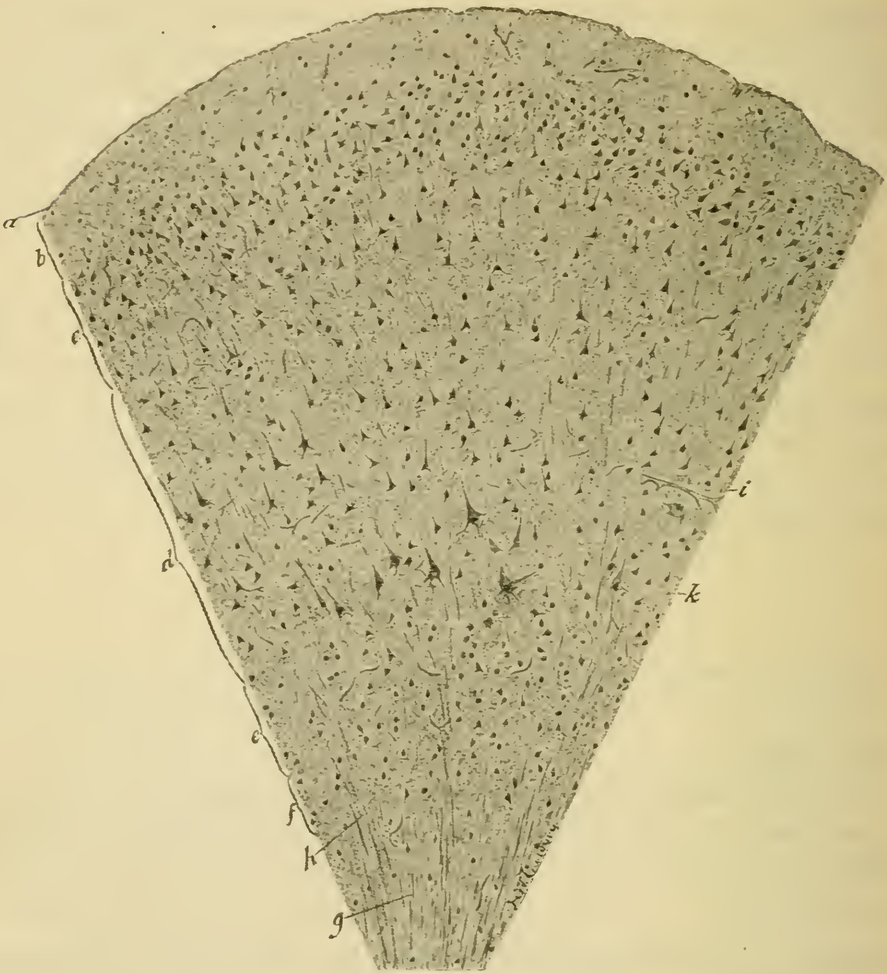


FIG. 267.—VERTICAL SECTION OF HUMAN CEREBRAL CORTEX.

a, Pia; *b*, molecular layer; *c*, small pyramidal cells; *d*, large pyramidal cells; *e*, layer of polymorphous cells; *f*, layer of fusiform cells; *g*, medulla; *h*, radial bundles of myelinated fibers in cortex; *i*, pial process; *k*, large pyramidal cell.

cells of the next layer that have entered the molecular layer. Their processes all remain in the molecular layer. Peripherally the neuroglia forms a rather dense layer as in the cerebellum.

2. The **outer polymorphous layer** consists of a narrow band of irregular cells that may be collected in small groups. These cells are polygonal, stellate and spindle-shaped and of the second type. The axones remain in the gray substance and the dendrites pass to the molecular layer where they form the tangential fibers. These cells are best developed in the hippochampal gyre (olfactory area) and are sometimes called the *cells of Cajal*.

3. The **layer of small pyramidal** cells is composed of several layers of cells, apical dendrites of which extend into the molecular layer while the other dendrites remain in this layer. Some of the axis cylinders partially pass to the molecular layer (second type) and *others* pass into the medulla (first type, or Deiter cell). In the *latter* case, the axis cylinders give off branches called *collaterals*. The *cells* themselves are small, measuring 10 to 12 microns in diameter, and triangular in outline. The *dendrites* arise from the *angles*, while the *axis cylinder* or *neurit*, has its origin at the *middle of the base*.

4. The **layer of large pyramidal** cells constitutes the widest and most important layer. The *cells* are usually 20 to 50 microns in diameter, though some may exceed this. The dendrites pass to the molecular layer, while the neurit becomes myelinated nerve fiber. These cells are, therefore, cells of the *first type*. Their outline is triangular, and the nucleus is large and prominent. This layer is usually as broad as all the others together.

Among the cells of this layer there are groups of very large pyramidal cells called the *giant cells of Betz;* some of these may also be in the small pyramidal cell layer. These are cells of the first type and their myelinated axones pass into the medulla and later form the *pyramidal tract* (*fasc. cerebrospinalis*). This constitutes the *pyramid* of the pons and all oblongatal regions and the *direct* and *crossed pyramidal tracts* of the spinal cord. It is a part of the direct motor pathway and is concerned with the movements of the voluntary striated muscles of the body.

5. The **inner polymorphus layer** is fairly broad and consists of cells of various shapes. These are small and large pyramidal, spindleshaped, oval, polygonal and granule cells. The *polygonal cells* seem to predominate. The *granule cells* are small and resemble those

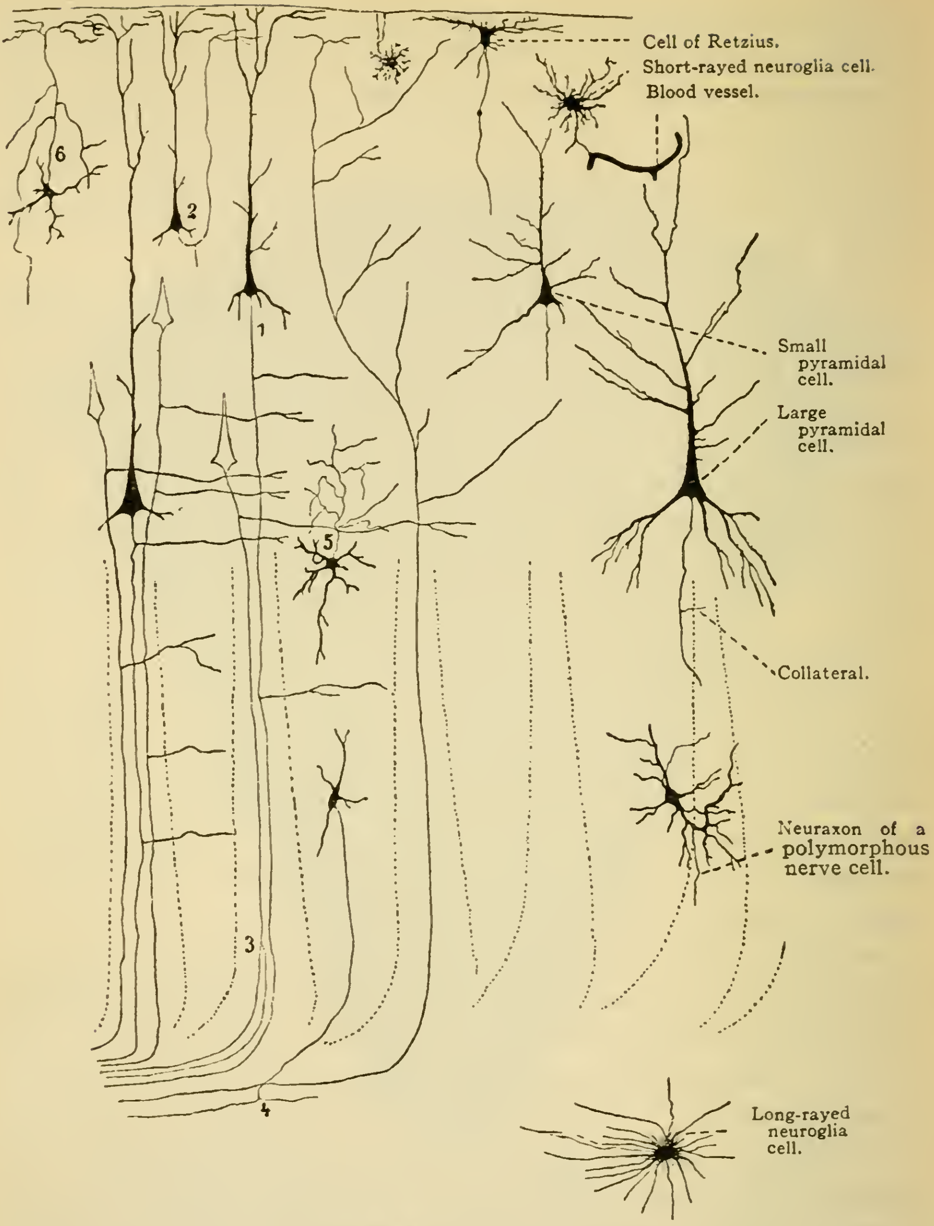

Cell of Retzius.
Short-rayed neuroglia cell.
Blood vessel.
6
2
1
Small pyramidal cell.
Large pyramidal cell.
5
Collateral.
Neuraxon of a polymorphous nerve cell.
3
4
Long-rayed neuroglia cell.

FIG. 268.—DIAGRAM OF THE CEREBRAL CORTEX.
The cells on the right are drawn from Golgi preparations of an adult man. (*Lewis and Stöhr.*)

of the cerebellum. The other cells are somewhat larger than the average cells of the small pyramidal layer. Most of the dendrites of these cells pass to the molecular layer while the others remain in this layer. The axones are of two types; some pass through the white for a short distance to the neighboring convolutions and these are the *association fibers;* others also become myelinated and enter the medulla and these are the *projection fibers* that pass to distant parts of the nerve system. These cells are of the first type.

The *cells of Martinotti* are second type cells that are found in all of the layers but are most numerous in the inner polymorphous layer. These are small polymorphous elements the axones of which pass to the molecular layer and assist in forming the tangential fibers.

In the last three layers, bundles of myelinated nerve fibers having a radial course are seen. They begin in the small pyramidal layer, increase in number as they approach the medulla, and contain, beside those fibers derived from the immediate cortical cells, others whose origin is not definite.

In addition there are other myelinated nerve fibers that form layers practically parallel with the surface. The **striation of Baillarger** is composed of such fibers that lie in the large pyramidal cell layer. The **striation of Bechtereff** consists of myelinated fibers between molecular and small pyramidal cell layers. These represent afferent fibers and are best marked in the temporal and occipital lobes (olfactory and visual areas).

The **cortex of the occipital lobe** (**cuneus** or **visual area**) consists of eight layers and these are: (1) *molecular,* (2) *outer polymorphous,* (3) *small pyramidal cell,* (4) *large pyramidal cell,* (5) *outer striation of Baillarger,* (6) *granule cell,* (7) *inner striation of Baillarger,* (8) *inner polymorphous layers.*

The layers of pyramidal cells are quite thin and the giant cells of Betz are absent. The granule cells are numerous in the outer layers and so may almost prevent a separation into layers in that part of the cortex. The striations of Baillarger are very distinct and the tangential fibers are well developed. Some very large multipolar cells called the *solitary cells of Meynert* occur within the last two layers.

The **medulla** consists of **myelinated nerve fibers** from various sources; those that pass to the periphery of the body from the pyramidal and polymorphus cells (**projection fibers**); others from the pyramidal cells that pass from one hemisphere to the other (**commissural fibers**); those that connect different areas of the same side (pyramidal cells), and whose axis cylinders are "T"-branched, and pass into the cortex sooner or later (**association fibers**); lastly, fibers that come from distant parts of the same or the other hemisphere, or other parts of the nerve system (**centripetal fibers**).

The various **pathways** will now be considered.

The **Direct Motor Pathway.**—This comprises but *two neurons.* The parts concerned are the *two pyramidal tracts* and the *motor portions of the cerebral and spinal nerves.*

The *pyramidal tract* of each side consists of afferent fibers that arise from the large and small pyramidal cells of the motor area of the cerebral cortex. They pass down through the corona radiata into the internal capsule occupying the middle portion thereof; they enter the crusta of the crus cerebri, then the tegmentum of the pons and the ventral area of the oblongata; in these three regions some of its fibers pass to the cerebral nerve nuclei of origin. At the caudal end of the oblongata 85 to 90 per cent. of the fibers *decussate* to the opposite side of the spinal cord as the *crossed pyramidal tract* and then end at various levels around the cells of the ventral horn. The remaining fibers continue down the same side of the spinal cord, as the *direct pyramidal tract,* to various levels in the cervical and upper thoracic region and then pass through the ventral, or white commissure, to end in the ventral horn of the opposite side. Ultimately all fibers decussate before they end. *This ends the first neuron.* The *second neuron* comprises the cells of the ventral horn and their processes that form the motor root of the spinal nerves, on the one hand, and in the case of the cerebral nerves comprises the cells of the various nuclei of origin and their processes that form the motor portion of the cerebral nerves. These axones pass out of the gray substance, become myelinated and ultimately end directly in a voluntary striated muscle fiber. *This is the end of the second neuron.*

First neuron, a pyramidal cell in the motor cortex of the cerebrum and its axone that forms a part of the pyramidal tract and that ends in a cerebral nerve nucleus, or the ventral gray of the spinal cord.

Second neuron, the cell in the nucleus of origin or in the ventral gray of the spinal cord, and its axone that ends in a voluntary striated muscle fiber.

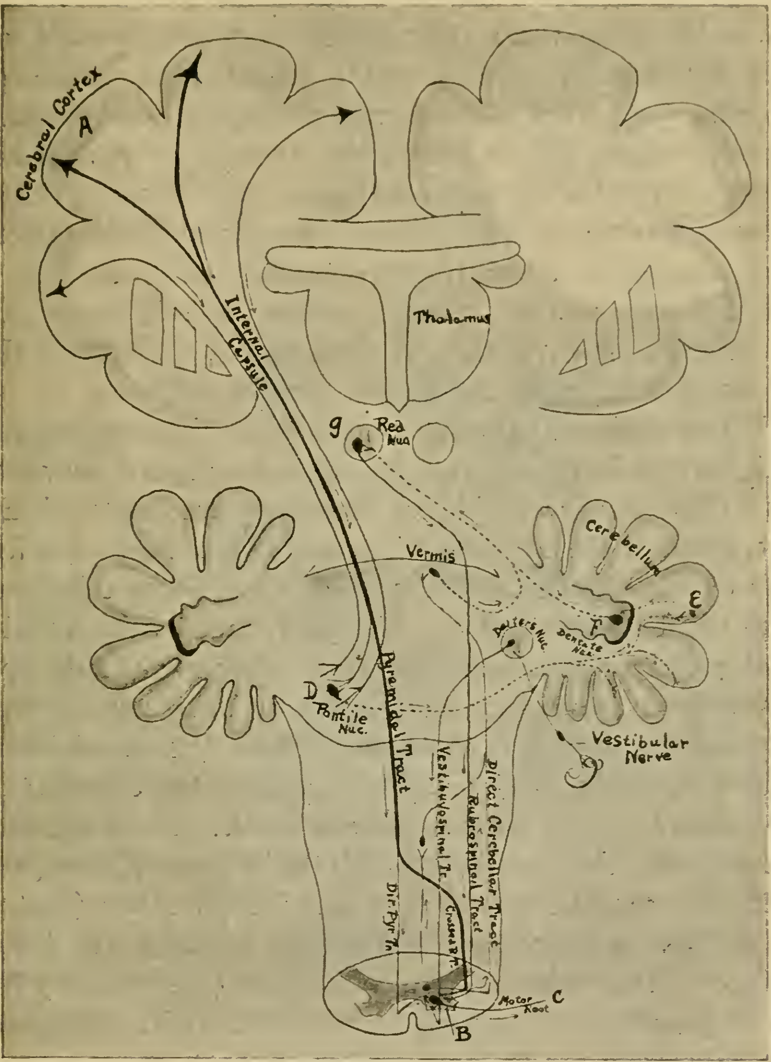

Cerebral Cortex
A
Internal Capsule
Thalamus
g
Red Nuc.
Vermis
Cerebellum
E
F
Deiters's Nuc.
Dentate Nuc.
D
Pontile Nuc.
Pyramidal Tract
Vestibulospinal Tr.
Rubrospinal Tract
Direct Cerebellar Tract
Vestibular Nerve
Dir. Pyr. Tr.
Crossed P.T.
Motor Root
C
B

FIG. 269.—DIAGRAM OF THE NEURONS IN THE DIRECT AND INDIRECT MOTOR PATHWAYS AND THE CONNECTIONS OF THE CEREBELLUM WITH THE BRAIN STEM AND THE SPINAL CORD.

Direct.—Neuron 1, *A* to *B*; neuron 2, *B* to *C*. Indirect.—Neuron 1, *A* (cerebral cortex) to *D*; 2, *D* to *E*; 3, *E* to *F*; 4, *F* to *g*; 5, *g* to *B*; 6, *B* to *C*. (*Radasch*, "*Manual of Anatomy*.")

The Indirect Motor Pathway.—This is more complex and comprises *six neurons*. *First*, from the motor area of the cerebrum (say right side) through the pyramidal tract, as above, to the *nuclei pontis* of the *same side* (right); *second*, from the nuclei pontis through the brachium pontis to the *cerebellar cortex* of the *opposite* (left) *side; third*, from the cerebellar cortex to the *dentate nucleus* of the cerebellum of the *same* (left) *side; fourth*, from the dentate nucleus through the brachium conjunctivum to the *red nucleus* of the *opposite* (right) *side; fifth*, from the red nucleus of that side through the *rubrospinal tract* to the cerebral nerve nucleus, or ventral horn of the spinal cord of the *opposite* (left) *side*. The fibers of the rubrospinal tract cross to the opposite side almost immediately after leaving the red nucleus. *Sixth*, from the cerebral nerve nucleus, or the ventral horn gray to the voluntary striated muscle fiber. As seen above there are *three crossings*, or *decussations*, the next to the last neuron terminating upon the opposite side of the body.

The Direct Sensor Pathway.—*In the trunk* the impulses arise at the periphery and are conveyed by the sensor spinal nerves to the *ganglia on the dorsal roots*. From there they are conveyed into the dorsal column of the spinal cord to end in the *nuclei gracilis* and *cuneatus* of the oblongata of the *same side*. Some collaterals are sent into the dorsal horn gray. *New fibers* arise in the nuclei cuneatus and gracilis and immediately cross, or *decussate* to the opposite side, forming the *sensor decussation*, that lies just above, or cephalad of the motor (pyramidal) decussation. These decussated fibers form the medial lemniscus that continues through the oblongata, pons and mid-brain to end in the *thalamus of that side*. From the thalamus *new fibers* convey the impulses through the internal capsule (occipital limb) to the *somatic sensor area of the cerebral cortex* (postcentral gyre). In this pathway *three neurons* are required, the *first*, from the surface to the nuclei gracilis, or cuneatus (the cell body lying in the dorsal ganglion); the *second*, from these nuclei to the thalamus; and the *third*, from the thalamus to the cerebral cortex.

Pathway for Touch, Temperature and Pain.—In the trunk and extremities, the *first neuron cells* lie in the ganglia of the dorsal roots of the spinal nerves. The peripheral fibers (dendrites) bring the impulses from the periphery (organ or skin) and it is then conveyed by the axone into the spinal cord through the dorsal root; the axones end in the gray substance of the dorsal horn. The *second neuron cells* lie here and their axones cross through the ventral gray commissure to the opposite side and form the spinothalamic tract in the spinal cord and in the oblongata they join the medial lemniscus to end in the thalamus. The *third neuron cells* lie in the thalamus and the

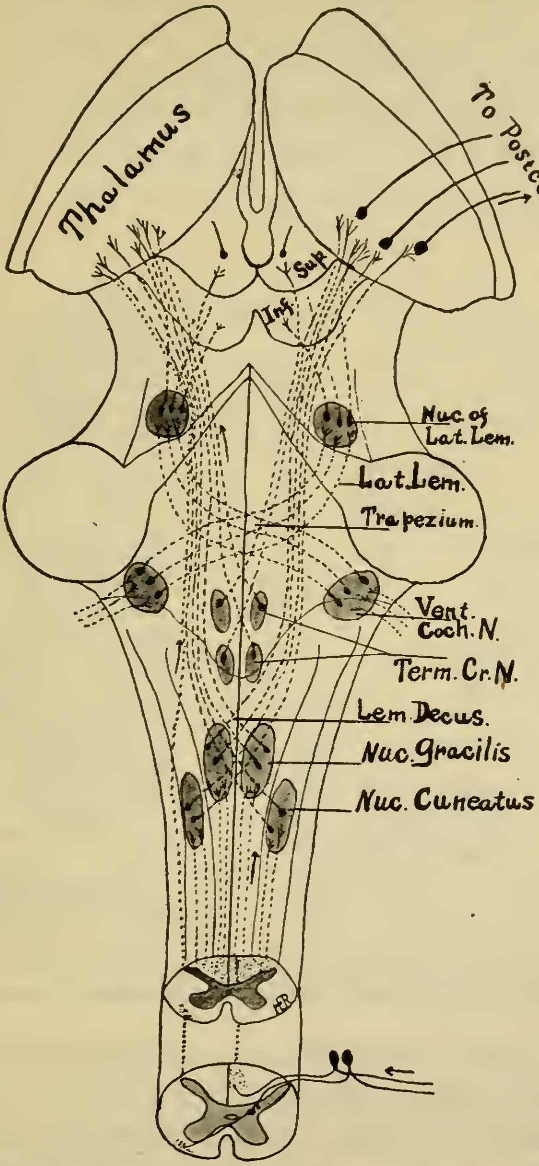

Thalamus
To Postcent. Gyre
Sup.
Inf.
Nuc. of Lat. Lem.
Lat. Lem.
Trapezium.
Vent. Coch. N.
Term. Cr. N.
Lem. Decus.
Nuc. Gracilis
Nuc. Cuneatus

FIG. 270.—THE ORIGINS, DECUSSATIONS AND COURSES OF THE FIBERS FORMING THE MEDIAL AND LATERAL LEMNISCI. DIRECT SENSOR PATHWAY. (*Radasch, "Manual of Anatomy."*)

axones pass through the internal capsule (sensor limb) to the cortical area of somatic sensibility (postcentral gyre). Some of the impulses of touch and contact sensibility are conveyed through the dorsal column of the spinal cord (same side) to the nucleus cuneatus and gracilis. The new fibers from these nuclei decussate and join the opposite medial lemniscus to end in the thalamus of that side; thus some of the sensibility fibers cross in the spinal cord at their entrance and others do not cross until the above nuclei have been reached.

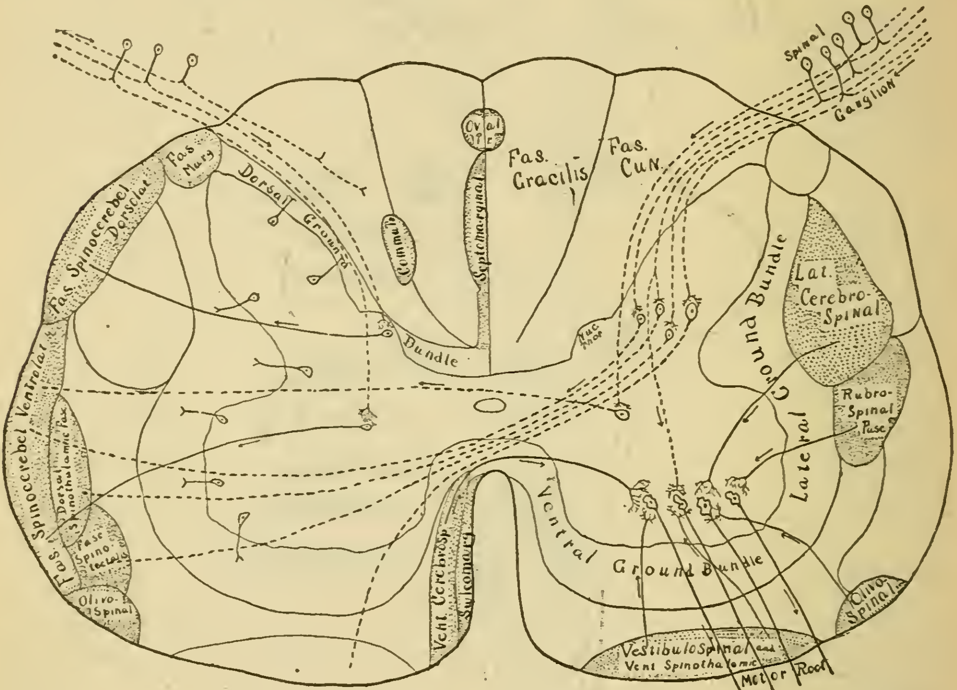

Spinal
Ganglion
Oval
Fas Mary
Dorsal Ground Bundle
Comma
Septomarginal
Fas. Gracilis
Fas. Cun.
Nuc thor
Fas. Spinocerebel Dorsolat
Fas. Spinocerebel Ventrolat
Dorsal Spinothalamic Fas
Fasc Spino tectale
Olivo-Spinal
Vent. Cerebrosp
Sulcomarg
Ventral Ground Bundle
Lateral Ground Bundle
Lat. Cerebro-Spinal
Rubro-Spinal Fasc
Olivo-Spinal
Vestibulospinal and Vent Spinothalamic
Motor Root

FIG. 271.—DIAGRAM OF THE VARIOUS TRACTS OF THE SPINAL CORD AND THEIR ORIGIN OR TERMINATION. (*Radasch, "Manual of Anatomy."*)

In the head most of the impulses are conducted to the nuclei of the trigeminus, glossopharyngeal and vagal nerves of each side to the ganglia of the sensor divisions; then they are conducted to the nuclei of termination of these nerves, in the fourth ventricle. This course constitutes the *first neuron.* The *second neurons* connect these nuclei with the thalamus by way of the medial lemniscus. The *third neurons* connect the thalamus with the cerebral cortex as above.

The **muscle sense (deep sensibility)** *impulses* of the trunk and extremities are conveyed as follows: The *first neuron* connects the periphery with the spinal cord where some of the fibers continue on the same side through the dorsal column to the nuclei cuneatus and gracilis. From here the fibers of the *second nenron* convey the impulses by way of the opposite medial lemniscus to the thalamus. The *third neuron* connects the thalamus with the cortical area.

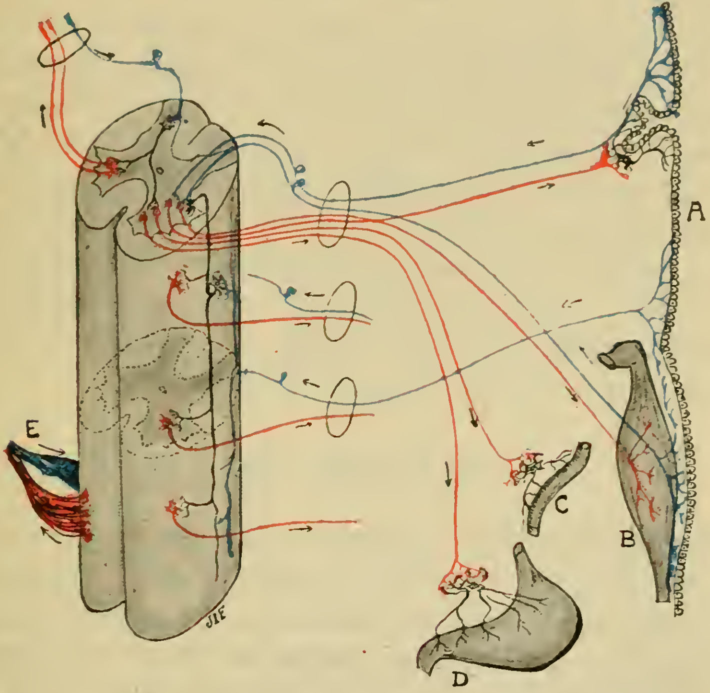


FIG. 272.—DIAGRAM OF THE STRUCTURES INVOLVED IN A REFLEX ACTION. *A*, Receptive surface; *B*, skeletal muscle; *C*, blood-vessel and sympathetic ganglion; *E*, spinal nerve attached to spinal cord. Red indicates motor and blue sensor impulses. (*Radasch*, "*Manual of Anatomy*.")

Some fibers pass from the nuclei gracilis and cuneatus to the cerebellar cortex; new fibers pass from here to the dentate nucleus of the cerebellum from which new fibers pass to the thalamus through the brachia conjunctiva.

Some of the fibers, only, of the first neuron, have the above course. Others, after entering the dorsal roots of the spinal nerves, do not enter the dorsal column but join the spinocerebellar tracts (ventral and dorsal superficial) to end in the cerebellar cortex of the same side. The impulses are then carried to the dentate nucleus and from here through the branchium conjunctivum to the opposite thalamus; from the thalamus the impulses are conveyed to the cerebral cortex.

Respiration.—Although respiration is apparently controlled by the respiratory nucleus that lies in the formatio reticularis of the oblongata, it is maintained by stimuli carried to this center by the blood vascular system and reflex impulses from the sensor portion of the vagus through cells in the nucleus of termination of the vagal nerve and by impulses from the higher respiratory centers. The *respiratory nucleus* is connected with the following motor nuclei: Facial, vagal, accessory, cervical plexus, phrenic, brachial plexus and thoracic nerves. Axones from the higher centers and from the sensor vagal nucleus end in the respiratory nucleus. The cells of the respiratory nucleus send their axones directly, or by means of collaterals, in the formatio reticularis, to the nuclei of the abovementioned motor nerves so that through this connection a number of cerebral and spinal nerves are caused to act.

OLFACTORY LOBE

The **olfactory** lobe, that portion of the nerve system devoted to the sense of smell, is comparatively small in man. There are *five* layers present, which are best marked in the central part of the organ. These are the **layer of peripheral fibers,** the **glomerular layer,** the **molecular layer,** the **layer of mitral cells** and the **granule layer.**

The **layer of peripheral fibers** consists of a plexus formed by the fibers of the **olfactory nerves.** These fibers are the axone processes of the nerve cells (olfactory cells) of the olfactory mucosa and are on their way to the next layer.

The **glomerular layer** lies internal the above, and is made up of peculiar round, or oval, bodies 100 to 300 microns in diameter. They are said to be masses of *interlacing telodendria* of the olfactory and mitral cells. In addition there are some Golgi cells (periganglion cells). This layer constitutes the end of neuron I and the beginning of neuron II of the olfactory pathway.

The **molecular layer** is made up of large and small spindle-shaped ganglion cells whose dendrites end in the glomeruli; the axis cylinders of the small cells (Golgi cells) pass to the **fifth** or **granule layer** and these cells are associative in function. The axones of the large (*brush*) cells pass to and through the granule layer to continue as a part of the olfactory tract with the fibers from the mitral cells. Both of these sets of axones represent neuron II.

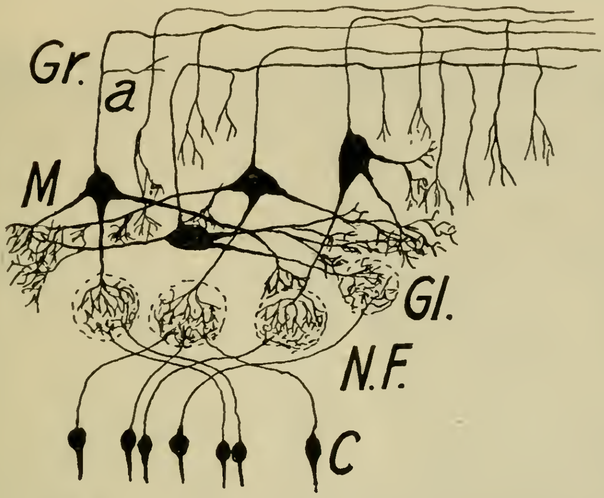


FIG. 273.—DIAGRAM OF THE OLFACTORY BULB AND THE CELLS OF THE OLFACTORY MUCOSA.

C, Olfactory cells; *N.F.*, layer of peripheral nerve fibers; *Gl.*, glomerular layer; M, layer of mitral cells; Gr., granular layer through which the axones of the mitral cells pass to the olfactory tract giving off collaterals to the bulb; *a*, afferent nerve fiber terminating in the olfactory bulb. (*After Schäfer.*)

The **layer of mitral cells** consist mainly of large **pyramidal** cells varying in size from 30 to 50 microns. Their dendrites pass to the glomeruli and the axis cylinders through the granule layer to the olfactory tract to end ultimately in the brain. Also neuron II.

The **granule layer** consists of *nerve cells* and *fibers*. The cells are stellate, ganglion elements, and peculiar granule cells; the *latter* appear to have no axis cylinders (amakrine cells). Some of the nerve fibers are derived from the mitral cells, some from the molecular layer, and others from the outside. The deeper bundles enclose granule and stellate cells.

THE HYPOPHYSIS

The **hypophysis,** or **pituitary body,** is a small organ that lies in the sella turcica of the sphenoid bone and is connected to the infundibulum of the diencephalon by a delicate *stalk.* It consists of *three portions,* the *anterior, posterior* and *intermediate portions.* These are surrounded by a common *capsule* of white fibrous tissue which is continuous with the tissue of the dura. The complete removal of the organ is said to be followed by death in a few days.

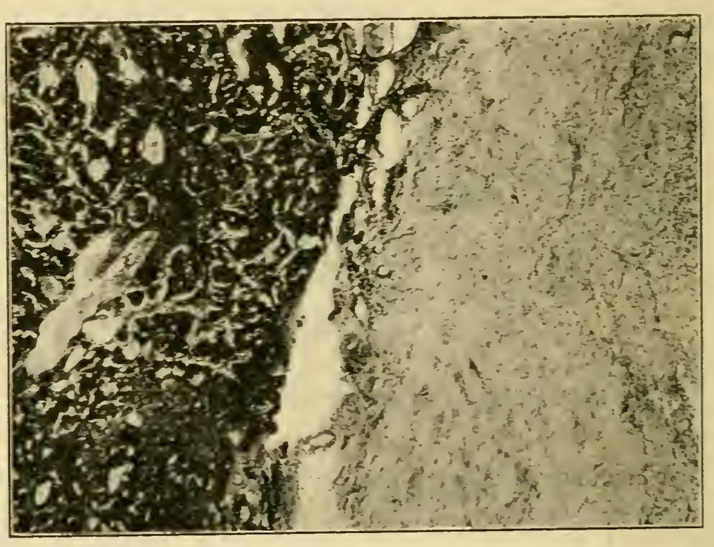


Fig. 274.—Section of Hypophysis showing its Epithelial (Left) and Neural (Right) Lobes with the Cleft-like Pars Intermedia between. (Photograph. Obj. 32 mm., oc. 7.5 X.)

The **pars anterior,** or **epithelial lobe,** consists of epithelial cells arranged in groups or chains; the latter are almost tubular in form. These cells are of three varieties: *clear, acidophilic* and *basophilic* elements. The *clear cells* consist of clear cytoplasm which is slightly granular. The nuclei are large and stain well. In the other cells the cytoplasm contains coarse granules but the nuclei are the same. On the one hand the granules respond to the *plasmatic stains* and on the other to the *basic stains,* hence acidophilic and basophilic cells. The latter are the more numerous. A small lumen may be noted within the cell groups. The capillaries are in close relation with the epithelial cells as in other glands of internal secretion. The *nerves* of this lobe consist of a very few fibers with numerous branchlets and ramifications that follow the arteries and are distributed mainly to the epithelial cells. Here they terminate in ball-like enlargements.

The **pars intermedia** occupies the interval that is represented by a cleft between the two main lobes, in lower animals. The epithelial cells are smaller and less granular. The cells of its anterior area are flattened while those of its posterior area are columnar in shape. Various-sized masses of *colloid*, or *hyalin material* are found here. This is not true colloid substance as is formed in the thyreoid body as it contains no iodin. It is derived from the cells of the pars intermedia and like the cytoplasm of these cells it contains glycogen.

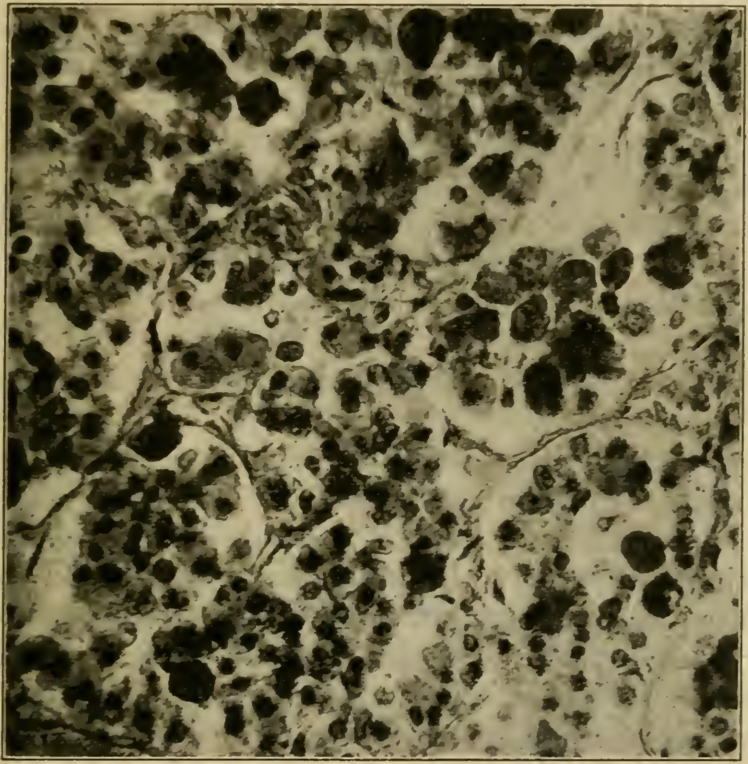


FIG. 275.—SECTION OF THE EPITHELIAL LOBE OF THE HYPOPHYSIS.
The large dark cells are the *basophils*; The large lighter cells are the *acidophils*; the smaller light cells are the *clear cells*. (Photograph. Obj. 4 mm., oc. 5 ×.)

The **pars nervosa** consists chiefly of neuroglia and a few nerve fibers that terminate in the epithelial portions. The glial cells may contain pigment that is of a lipoid nature. Hyalin substance is found in this lobe most abundant near the pars intermedia. It may extend into the infundibular cavity on its way to the third ventricle. This hyalin substance comes from the pars intermedia and seems to be sent to the cerebrospinal fluid via the third ventricle.

The *arteries* reach the organ by means of the infundibulum. As they reach the pars intermedia branches pass to the pars anterior and form plexuses around the cell groups. The capillaries are most numerous in the pars anterior and are of the sinusoidal type. The *veins* have a corresponding course.

The *lymph spaces* are numerous. In the pars anterior they surround the epithelial cells and lead to the subarachnoid space and the perivascular lymph spaces of the base of the brain. As mentioned previously the lymph spaces of the pars nervosa and intermedia seem to communicate with the third ventricle.

THE EPIPHYSIS

The **epiphysis,** or **pineal body,** is a small, apparently unimportant organ in man. In some lower animals, it is a *visual organ.* This rudimentary structure consists of a number of tubules lined by *polygonal cells* supported by fibrous tissue and neuroglia in the lower part. These tubules contain the **brain sand,** or **acervulus cerebri,** peculiar concretions of phosphate and carbonate of magnesium, ammonium and calcium, which are not limited to this body, however, but may be found in other portions of the nerve system.

The *circulation* of the nerve system is carried on chiefly by the vessels in the pia. In the **cerebrum,** the vessels of the cortex enter vertically, and form a close plexus of capillaries most plentiful where the cells are. Those intended for the medulla are larger, and, passing through the cortex, form capillary networks between the fibers and parallel to them. Other branches supply the basal ganglia.

In the **cerebellum,** the capillaries are few in the outer portion of the molecular layer, but in the granule layer and around the cells of Purkinjé, close meshes are formed.

In the **spinal cord,** there are two sets of vessels, those that enter at all points of the periphery and supply chiefly the white matter, and those derived from the artery lying in the ventromedian fissure; the latter set goes to the gray substance. The smaller peripheral vessels remain in the white substance, and run parallel to the fibers, while the larger penetrate the gray substance and supply the outer part. The artery in the fissure sends branches into the gray commissure; these divide right and left, and form dense plexuses in the gray substance. The arteries of the spinal cord are terminal as their capillaries do not anastomose.

The blood is collected by *venous* radicals that have the same general course. Those of the brain empty into the large *venous sinuses* of the dura. In the spinal cord they form the large *ventral* and *dorsal median veins*.

Lymph vessels are absent in the brain and spinal cord. Lymph spaces, *pericellular* and *perivascular* are very numerous and communicate with the subarachnoidean lymph space. The *subarachnoidean lymph space* continues as the *perivascular lymphatics* that accompany the blood-vessels.

CHAPTER XVIII

THE EYEBALL AND LACRIMAL SYSTEM

The **eyeball** (*bulbus oculi*) is one of the most important organs of the special senses. The eyeball occupies the anterior portion of the orbital fossa and is protected by the orbital margins and the eyelids. The anteroposterior and transverse diameters are 24 mm. while the vertical dimension is 23.5 mm. so that the eyeball is not quite a sphere at the equator. At birth the eyeball is about 17.5 mm. in diameter and is nearly spherical in shape. It increases about 3 mm. between birth and puberty and soon thereafter attains its adult shape and size.

The apparent difference in the size of the eyeballs of different individuals is not due to a real difference in size but to a difference in prominence of the eyeball and width of the palpebral fissure. When viewed from the side the eyeball is seen to consist of parts of two spheres. The smaller, anterior corneal portion (about one-sixth) represents part of a sphere of 14 mm. diameter, while the larger posterior portion (five-sixths) represents the greater part of a sphere of 24 mm. diameter. The *optic axis* is represented by a line connecting the anterior and posterior poles, that is the central points of anterior and posterior curvatures, respectively. The *equator* is the line around the eyeball midway between the poles. The *visual axis* is a line that passes from the first nodal point of the cornea to the fovea centralis of the retina.

The eyeball is called the organ of vision (*organon visus*). In reality it makes an image like a camera, while nerve impulses that are generated by the cells of the retina travel to the brain and these impulses are then translated into photic impressions.

The eyeball is operated by a number of *extrinsic muscles* that are of the voluntary striated variety. Within the eyeball are some smooth, *intrinsic muscles* that are concerned with the actions of the iris and the process of accommodation.

The eyeball alone does not occupy the entire orbit but addition the extrinsic muscles, orbital fat, capsule of Tenon, vessels and nerves are found here. The *orbital fat* forms a soft bed or cushion for the eyeball and the quantity differs in various individuals. If it is above the average amount the eyeballs protrude somewhat; if it is less than the average condition then the eyeballs have a sunken appearance. This is especially noticeable after a long illness and the sunken appearance is due to the fact that some of the fat here has been used as food. During convalescence the fat is restored.

The *capsule of Tenon* (*fascia bulbi*) is a lymph space, or bursa within which the eyeball moves as free from friction as possible. This lies behind the equator of the eyeball and consists of a double layer of a serous membrane which are continuous with each other. This covers the posterior portion of the eyeball and extends as far forward as the reflection of the conjunctiva. The layers are practically in apposition and are pierced posteriorly by the optic nerve and is continued thereon. It is likewise pierced further forward by the tendons of the ocular muscles and is prolonged upon each as a tubular sheath. That portion of the fascia under the eyeball is formed like a swing, or hammock and seems to support the eyeball; it has therefore been called the *suspensory ligament.*

The eyeball is composed of **three coats** and contains **four refractive media.** The **coats** are the **external,** or **corneo-sclera;** the **middle,** or **choroid, ciliary body** and **iris;** and the **internal,** or **retina.**

The refractive media are the **cornea,** the **aqueous** and **vitreous humors** and the **lens.** Of these, the cornea and lens *alone* are of importance.

The **corneo-sclera** is the protective and transparent coat of the eyeball.

The **sclera** constitutes about five-sixths of this coat. It is composed of coarse bundles of white fibrous tissue that interlace to form a dense, tough coat. These bundles although arranged chiefly longitudinally and transversely interlace somewhat. Between the bundles are spaces that contain large, stellate cells. These spaces communicate with the lymph spaces within the cornea. On its external surface, the sclera is in relation with the **capsule of Tenon,** and, anteriorly, the **conjunctiva.** To it are attached the ocular muscles.

The visible portion of the sclera constitutes the *white of the eye;* in the young it may be bluish in color, in the adult it is white, while in old age it may show yellowish patches.

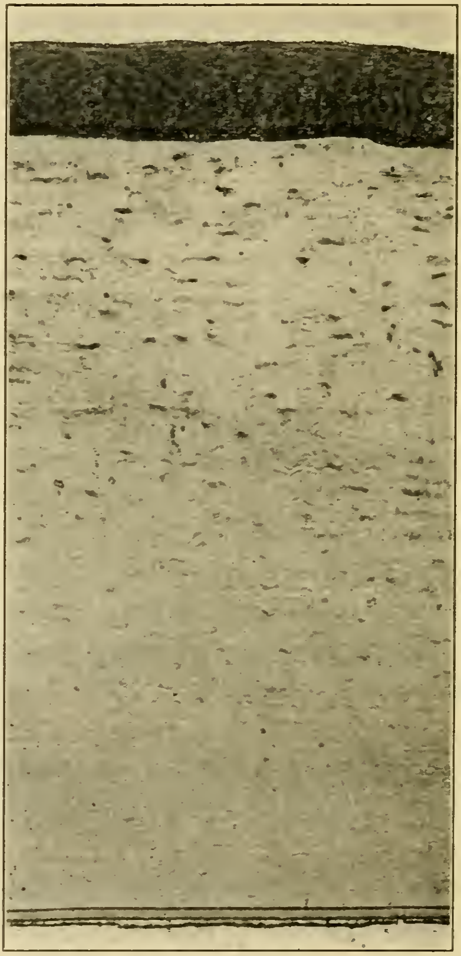


Fig. 276.—Section of the Human Cornea Showing the Various Layers. (Photograph. Obj. 16 mm., oc. 7.5 X.)

Between the sclera and the choroid there is a lymph space called the *subscleral space.* Here the tissue is loosely arranged and the spaces formed are lined with endothelial cells. This reticular membrane may be separated from the sclera except in the region of the optic nerve exit. The connective tissue cells contain a brownish pigment and this membrane is called the *lamina fusca.* At the exit of the optic nerve the sclera is pierced by a number of small openings through which the fila of the optic nerve pass; this forms a sieve-like area in the sclera and is called the *lamina cribrosa.* At this region the sclera is thickest. Pigmentation of the cells occurs here as well as at the corneoscleral junction.

The **cornea** is a specialized portion of the sclera modified for the transmission of light. It is practically a convavoconxex lens with the convex side externally placed. It is about 1 mm. in thickness. The posterior, or internal surface is more extensive than the anterior as the transition from cornea to sclera begins sooner on the external surface. It consists of **five layers: anterior epithelium, anterior limiting membrane, substantia propria, posterior limiting membrane,** and **posterior endothelium.**

The **anterior epithelium** is a continuation of the epithelium of the conjunctiva. This is of the *stratified squamous* variety, and the *tunica propria* beneath is not papillated. The layers of cells, usually five or six, are more numerous at the corneo-scleral junction than in the center. The basal cells are long and columnar, and possess processes that extend into the anterior elastic lamina, while the external cells are squamous. The middle layers are prickle-cells, and the spaces between are lymph channels. Sensor nerve fibers are numerous in the epithelial layers.

The **anterior elastic lamina,** or *Bowman's membrane,* is a clear prominent band serving as a basement membrane to the epithelial cells. Although called elastic it does not consist of elastic tissue. It is thickest in the center of the cornea and becomes thinner as the corneoscleral junction is approached, where it continues as the thin basement membrane of the conjunctiva. It is unusually prominent for a basement membrane and because, like elastic tissue, it does not respond to the ordinary stains the older observers were lead to believe that it consisted of elastic tissue. It does not respond to the elastica stains.

The **substantia propria** forms the bulk of the cornea, and consists of a number of layers (about sixty) of white fibrous tissue arranged parallel to one another. It is due to this arrangement that this organ is transparent. In the center of the cornea the bundles of fibers of the successive layers cross one another at right angles. In addition to these fibers, there are others that penetrate the organ at a right angle to the layers, and bind all together. These are the *perforating fibers.* Between the various layers are a large number of irregular spaces called the **corneal lacunæ.** These contain large stellate cells that are the original connective-tissue cells of the organ. They are the **corneal corpuscles.** The spaces communicate with one another by means of little canals called **canaliculi,** into which their processes extend. These spaces are readily shown by the gold chlorid method of staining.

The **posterior limiting membrane,** or **membrane of Descemet,** is analogous to the anterior membrane; unlike this one, however, it is thicker peripherally than centrally, and seems more independent of the substantia propria than the anterior. It does not respond to the elastica stain, and, consequently, is not made up of elastic tissue, as its name would seem to indicate. It becomes the *pectinate ligament.* According to Stöhr the pectinate ligament consists of fibers passing from the iris to the cornea. It is said to prevent the passage of lymph from the anterior chamber to the corneal spaces.

The **endothelial layer** consists of a single layer of well-defined regular cells, which cover the posterior surface of this organ, and continue over the anterior surface of the iris. These cells are hexagonal, and possess a fibrillar cytoplasm that seems to extend through several layers.

The cornea possesses *blood-vessels* during the developmental period. These, however, disappear before birth, so that none are then present. Lymph, which circulates through the many large spaces and canaliculi, nourishes the cornea. Lymphatic vessels are absent.

The sclera possesses but few vessels, and these are found chiefly at the corneo-scleral junction, where a circular network is formed. They anastomose with the vessels of the choroid.

The *nerves* are *sensor*; at the corneo-scleral junction a circular plexus is formed, from which fibers pass into the substantia propria, while others penetrate the anterior elastic lamina to pass into the epithelial layer. Some of these fibers extend almost to the surface. Bulbs or corpuscles occur near the scleral margin of the cornea.

The **middle coat,** or tunic, also called the **uveal tract,** is the vascular coat. It contains the main vessels of the eyeball, except the central artery of the retina, and consists of the **choroid, ciliary body** and **iris.**

The **choroid** is the vascular portion, and is divided into three layers, the **stroma layer,** the **choriocapillaris,** and the **glassy membrane,** from without, inward.

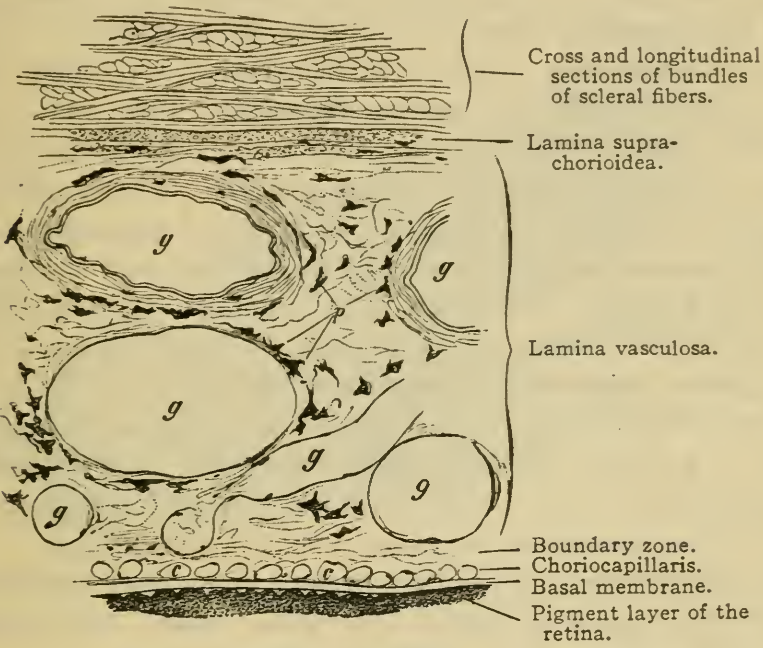

Cross and longitudinal sections of bundles of scleral fibers.
Lamina suprachorioidea.
Lamina vasculosa.
Boundary zone.
Choriocapillaris.
Basal membrane.
Pigment layer of the retina.
g
g
g
g
g
g
c
c

FIG. 277.—VERTICAL SECTION THROUGH A PART OF THE HUMAN SCLERA AND THE ENTIRE THICKNESS OF THE CHOROID. × 100. (*Lewis and Stöhr.*)
g, Large vessels; *p*, pigment cells; *c*, cross-section of capillaries.

The **stroma layer** is sometimes referred to as the layer of large vessels, as they are found only in this portion. It consists, externally, of delicate fibers that connect with those of the subscleral tissue and form a complete space, the **suprachoroidal,** or **subscleral lymph space.** In this tissue are found pigmented connective-tissue cells, and it has received the name of **lamina suprachoroidea.** This consists of a delicate meshwork of fibers some of which pass to the lamina fusca of the sclera and others to the stroma layer of the choroid. Pigmented connective tissue cells are numerous; they may be scattered or in groups. Their cytoplasm contains coarse brownish granules of pigment. The main portion of the stroma layer consists of bundles that are closely arranged. The networks formed by these are the *venous* trunks, *externally*, and the *arterial* trunks, *internally;* the *latter* are accompanied by bundles of smooth muscle tissue. Pigmented cells exist between the bundles.

The inner portion of this layer is a narrow dense zone and is called the **boundary zone**; the bundles are arranged into several layers in herbivorous animals, so as to give a peculiar *metallic reflex*, and constitute the **tapetum fibrosum.** This area is usually free from pigment cells. In the carnivorous animals the fibers are replaced by distinct cells that contain crystals. The metallic reflex, however, is the same. This forms the **tapetum cellulosum.**

The **choriocapillaris** contains little stroma, and is composed chiefly of a dense capillary plexus. No pigment cells are seen. The capillaries are most numerous around the macula latea.

The **glassy membrane** or **membrane of Bruch,** lies at the inner boundary of the choroid, and consists of refractile, homogeneous tissue. It is a very thick basement membrane, and supports the pigmented cells of the retina, which form small depressions in its surface. This membrane increases in thickness in old age.

The choroid extends to the **ora serrata,** a peculiar, serrated line, at which the neural portion of the retina ceases. At this point, the choroid continues as the **ciliary body.**

The **ciliary body** is composed of three main portions, the **ciliary ring,** the **ciliary processes** and the **ciliary muscle.** It is thicker than the choroid, which is due especially to the addition of the muscle tissue.

The **ciliary ring** is practically the continuation of the stroma layer of the choroid and the glassy membrane, and consists of dense white fibrous tissue, which forms a circular band about 4 mm. in breadth. The outer bundles mix with the bundles of fibers of the ciliary muscle. The vessels have a longitudinal course.

The **ciliary processes** are projections of the stroma, covered by pigmented epithelial cells, from 60 to 80 in number. They arise at the junction with the choroid, and extend toward the iris, increasing in height, ending abruptly at that point. At this place they are about 1 mm. in height. Each process consists of a core of stroma (connective tissue) supporting blood-vessels and covered by the pigmented epithelial cells of the retina, the **pars ciliaris retinæ.** This is said to be the most vascular region of the eyeball. These cells rest upon a continuation of the glassy membrane. There are two layers, the *outer*, or *basal* of which consists of low columnar or cuboidal elements that are the continuation of the true pigmented cells of the retina. The cytoplasm is usually filled with brownish pigment granules but the nucleus is not invaded. The *inner* layer is composed of cells that are columnar, possess little or no pigment. The cytoplasm is usually clear or only slightly granular and may show fibrillation or contain delicate rods. These cells are the representative of the optical portion of the retina. In places gland-like evaginations of the pigmented epithelium are noted. These are the *so-called ciliary glands.*

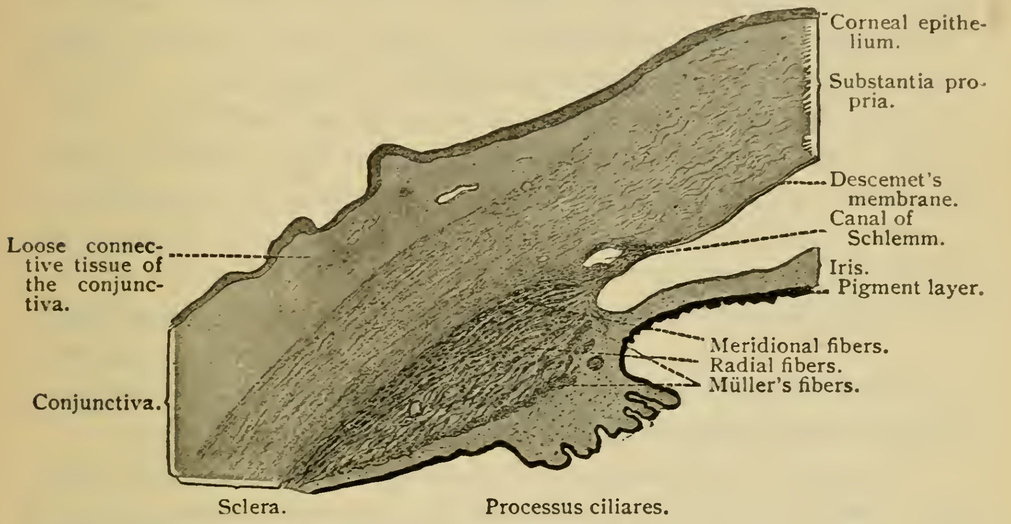

Corneal epithelium.
Substantia propria.
Descemet's membrane.
Canal of Schlemm.
Loose connective tissue of the conjunctiva.
Iris.
Pigment layer.
Meridional fibers.
Radial fibers.
Müller's fibers.
Conjunctiva.
Sclera.
Processus ciliares.

FIG. 278.—MERIDIONAL SECTION OF THE HUMAN CILIARY BODY. × 20. (*Böhm, Davidoff and Huber.*)

The **ciliary muscle** is of the nonstriated variety, and lies external to the ciliary ring, just beneath the sclera. The fibers are arranged in **meridional, radial** and **circular** sets. The **meridional** are the *outermost*, and extend from the canal of Schlemm, in the corneoscleral junction, to the ciliary ring. The fasciculi vary in length and represent the bulk of the ciliary muscle. These are the *tensor muscles* of the choroid. The **radial** fibers, which compose the *middle* layer, extend peripherally, and, spreading fan-like, are inserted into the ciliary ring and processes. These fibers are less numerous and run a shorter course. Although they start out like the meridional fibers they soon are arranged parallel to the radii of the eyeball. The **circular** fibers are the *inner* ones, and their direction is *equatorial*. The fibers are arranged in small bundles that are mixed with the radial fibers and pectinate ligament. These fibers are said to be increased in number in hypermetropic eyes and reduced or absent in myopic eyes. They constitute **Müller's ring-muscle.** The ciliary muscle is important in the process of accommodation.

The ciliary region is indicated, externally, by a band about one-fourth of an inch broad, starting at the corneoscleral junction. It is called the danger zone of the eyeball, as injuries here usually result fatally to sight.

The **iris** is the continuation of the stroma layer and glassy membrane of the choroid. It receives also the posterior lamina and the endothelium of the cornea, and consists of the **anterior endothelium, stroma layer, posterior lamina** and **pigment layers.**

The **anterior endothelium** is a continuation of that of the cornea, and covers the anterior surface of the iris. The cells are neither so regular nor distinct as those of the cornea. In areas they are wanting and permit of a direct communication between the intercellular spaces of the iris with the anterior chamber.

The **stroma layer** is composed chiefly of a coarse network of white fibrous tissue, some of which is circularly arranged around the blood-vessels, which possess no muscular coat. Anteriorly, this stroma is very much reticulated and forms a support for the endothelial cells. According to some authors, this portion constitutes an *anterior limiting membrane.* The connective tissue cells are unusually numerous. In the stroma layer, pigment cells are found in varying quantities; in gray eyes, very few are seen; as the color passes to blue, brown and black, the number increases, the last possessing the most. In albino eyes not only are the pigmented connective cells of the stroma layer absent, but the pigment that is usually present in the posterior epithelial cells continued from the retina is also absent. As a result of this, the retinal blood-vessels cause a peculiar red reflex, the *retinal reflex*. In the other eyes the pigment obscures it.

The stroma is quite vascular; the large vessels have a meridional direction. These vessels usually produce slight ridges upon the anterior surface of the iris and between these are slight grooves. The anterior surface has therefore an uneven appearance.

In the stroma is found muscle tissue of the involuntary nonstriated variety. This is arranged **circularly** and **radially.** The **circular** fibers are near the anterior part of the iris, and contract the pupillary aperture when stimulated; these form the **sphincter pupillæ** muscle. The **radial** fibers lie near the posterior part, and when they contract, the pupillary aperture is dilated; they constitute the **dilatator pupillæ** muscle. According to Schäfer this muscle covers the posterior surface of the iris stroma as a single layer of thin, flat cells. At the periphery of the iris is two to three cells thick. No basement membrane intervenes between this muscle and the pars iridica retinæ.

The **posterior limiting membrane,** or **membrane of Bruch,** is a continuation of the glassy membrane. It supports the pigmented cells, the **pars iridica retinæ.**

The **pigmented layer,** a continuation of the pars ciliaris retinæ, and called the **pars iridica retinæ,** is usually pigmented, and consists of two layers of cells. The cells are filled with pigment and with adults the individual elements cannot be distinguished. It continues to the anterior margin of the pupil.

The **pupil** is the aperture in the iris. Its size is regulated automatically by the amount of light entering.

The iris is an automatic curtain that is suspended in the aqueous humor. It regulates the amount of light that enters the lens and divides the anterior and posterior chambers from each other.

The **corneoscleral junction** is the region in which cornea, sclera, ciliary body and iris come together. The sclera passes over into the cornea, but the line of transition is not abrupt, but gradual, and forms an oblique line that extends from before, backward and inward so that the posterior surface of the cornea is greater in extent than the anterior surface. Beneath the posterior margin, usually within the sclera, is a *circular canal*, the **canal of Schlemm,** which extends around the corneoscleral junction. Through this canal the lymph of the cornea, spaces of Fontana and anterior chamber enters the scleral venules. In this region, the membrane of Descemet is seen to divide into a large number of fibers that extend to the base of the iris. Some of the ciliary muscle fibers arise here and assist in forming a network. Between the fibers are found many intercommunicating spaces called the **spaces of Fontana.**

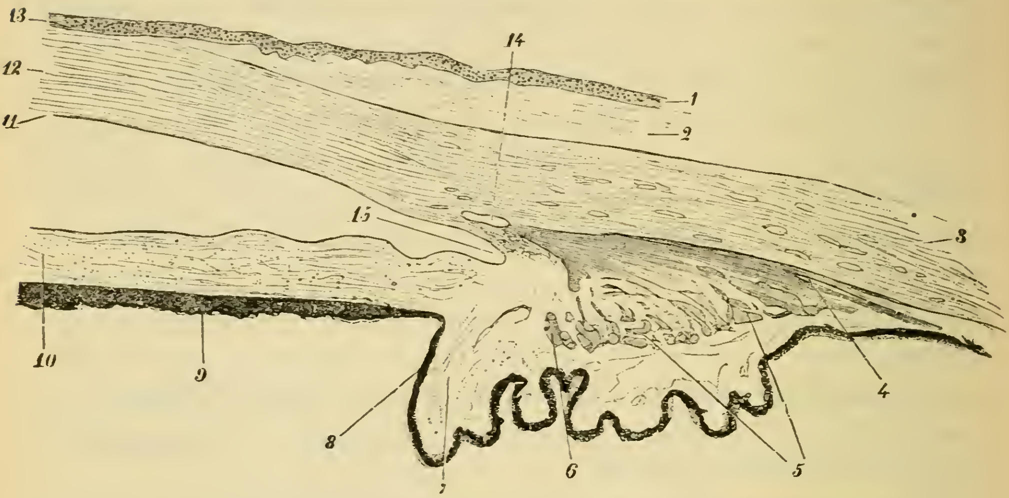


FIG. 279.—CORNEO-SCLERAL JUNCTION OF MAN.

1, Epithelium; 2, connective tissue of conjunctiva; 3, sclera; 4, 5, 6, 7 and 8, ciliary body; 4, meridional; 5, radial; 6, circular fibers of ciliary muscle; 7, ciliary process; 8, pars ciliaris retinæ; 9, pars iridica retinæ; 10, stroma of iris; 11, posterior elastic lamina of cornea; 12, substantia propria; 13, epithelium; 14, canal of Schlemm; 15, angle of iris, or infiltration angle. (*Stöhr's Histology.*)

These spaces lie around the angle formed by the cornea and iris, called the **infiltration angle,** and communicate with the anterior chamber and the canal of Schlemm. The network is called the **pectinate ligament,** and is covered by endothelial cells. It is more prominent in some lower animals than in man.

THE RETINA

The **retina** forms the **internal,** or **neural coat** of the eyeball. It may be divided into two portions, the **pars optica,** that portion capable of vision, and the **pars ceca,** or the blind part, possessing no nerve elements. The latter portion is further subdivided into **pars ciliaris** and **pars iridica retinæ.** The simplest division of the retina, however, is **pars optica, pars ciliaris** and **pars iridica retinæ.**

The **pars optica** lines almost the entire optic cup, and extends forward to the end of the choroid. Here the neural portion ceases, and the coat becomes abruptly thinner, and forms an irregular serrated line, the **ora serrata.** From this point, the last two portions of the retina continue.

The optical portion consists of *eleven layers*, counting the pigmented layer. These layers are classed as **neuro-epithelial** and **cerebral.** The **neuro-epithelial** portion consists of the first layers within the pigment layer, and the **cerebral** portion the remaining divisions. The pigmented part is derived from the outer layer of the optic cup, and the other parts from the inner layer.

Optic Vesicle	**Retinal Layer**	**Classes**
1. **Outer Layer.**	Pigmented Layer.	**PIGMENT LAYER.**
2. **Inner Layer.**	Layer of rods and cones.	
	External limiting membrane.	**NEURO-EPITHELIAL LAYER.**
	Outer granular layer.	
	Henle's fiber layer.	
	Outer reticular (molecular).	
	Outer ganglionic (inner granule).	
	Inner reticular (molecular).	**CEREBRAL.**
	Inner ganglionic.	
	Nerve Fibers.	
	Internal limiting membrane.	

1. The **pigment layer** of the retina consists of a single layer of polyhedral cells that contain a black, granular, mobile pigment (*fuscin*). The position occupied by this pigment depends upon whether the eyeball was fixed in or during the exclusion of light. The cells possess some processes that extend around the bodies of the rod and cone cells. If the eyeball is fixed in the presence of light the pigment granules seem to collect in these processes while the remainder of the cytoplasm is practically free. If the eyeball be removed and fixed in the dark the pigment granules lie in the

body of the cell. The *nucleus* occupies that portion of the cell near the basement membrane (glassy membrane of the choroid) and is devoid of these pigment granules. These pigment granules apparently absorb the excess rays of light and convert them into

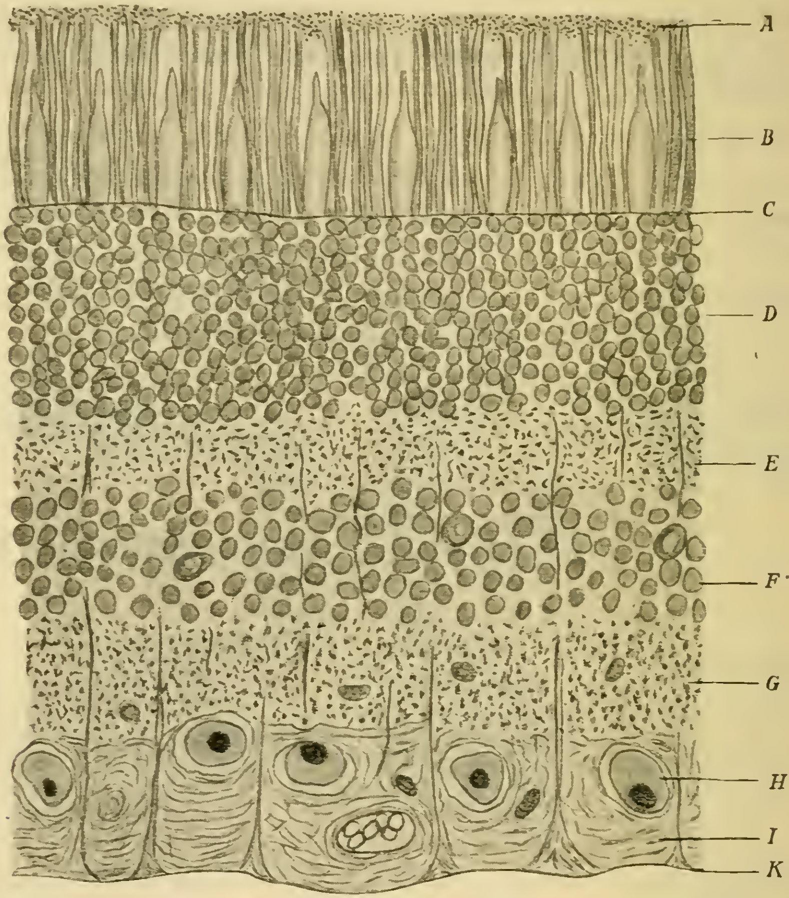


FIG. 280.—SECTION OF HUMAN RETINA. (*After Piersol.*)

A, Part of pigment layer; *B*, layer of rods and cones; *C*, external limiting membrane; *D*, (outer) nuclear layer; *E*, outer reticular layer; *F*, outer ganglionic layer; *G*. inner reticular layer; *H*, inner ganglionic layer; *I*, layer of nerve fibers; K, inner limiting membrane. Henle's fiber-layer is not represented.

heat and are also said to replace the rhodopsin of the rod cells as this become bleached through the action of the light. These cells continue over the ciliary body and iris as the pars ciliaris and pars iridica retinæ. In the iris both layers are pigmented but not in the ciliary region. This layer of cells is derived from the outer layer of the optic cup.

The neuro-epithelial elements and the nerve cells and fibers are supported by *neuroglia*, of which there is a great deal present, but this is unevenly distributed.

2. The **layer of rods** and **cones** is the most important of the retina.

The **cone cells** consist of *cone-body* and *cone-fiber*. The *cone-body* varies in length and consists of two segments, *outer* and *inner*. The *outer segment* is the shorter, conical and may be striated. This portion rests upon the external limiting membrane and apparently consists of discs. The *inner segment* is striated and flask-shaped. The cytoplasm of this portion, at its junction with the outer segment, is granular while the remainder is fibrillar. The *cone-fiber* is the continuation of the cell-body, lies within the internal limiting membrane and passing inward terminates in the outer reticular layer. At its junction with the body it is slightly enlarged (*cone-foot*) and this portion contains the nucleus. The nucleus stains less deeply than the nucleus of the rod cell. The length of the cones varies in different parts of the retina. Near the ora serrata they are about 22 microns long; midway between the ora and the optic papilla, 31 microns; at the edge of the fovea centralis, 44 microns; in the center of the fovea, 88 microns. The cone bodies average about 35 microns in length and 7 microns in thickness.

The **rod bodies** are longer on the average than those of the cone cells and more nearly uniform in size. They average about 60 microns in length and 2 microns in thickness. Each consists of an *outer* and an *inner segment* which react differently to stains. The *outer segment* does no respond well to the ordinary stains and is anisotropic and is brighter in appearance than the inner segment. This portion contains the *rhodopsin*, or *visual purple*, which after having been bleached by the action of light is rapidly replaced by the pigment cells of the retina. This segment is said to be surrounded by a delicate neurokeratin sheath. The *inner segment* is somewhat spindle-shaped and at the junction with the outer segment the cytoplasm is granular. The rest of the cytoplasm is fibrillar. The *rod-fiber* is the continuation of the cytoplasm and contains the nucleus. The fiber is far more delicate than that of the cone cell, markedly varicose and the various nuclei are at different levels. In the case of the nuclei of the cone cells they are all placed at the same level and lie next to the limiting membrane. The nuclei of the rod cells are far more numerous than those of the cone cells and so are scattered to the best advantage in the outer nuclear layer. The nuclei of the rod cells are peculiar in that the chromatin seems to be distributed in the form of several transverse bands, giving the nucleus, thus, a striated appearance. The rod-fiber terminates in the outer reticular layer.

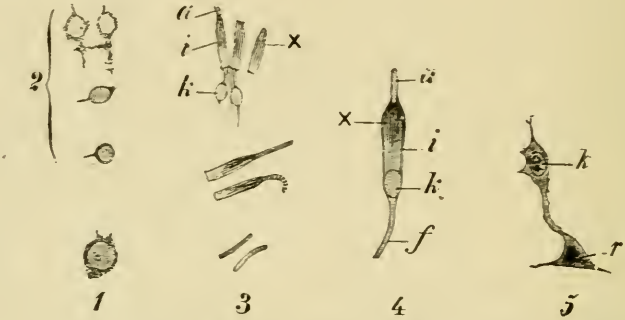


Fig. 281.—Cells from Retina of an Ape. (*Stöhr's Histology.*)

1, Cell of ganglionic layer. 2, Cells of inner granule layer. 3, Rod-cells—*a*, Outer segment; *i*. inner segment; *k*, rod-granule; *x*, fiber apparatus. Below are rod-cells and fragments. 4, Cone-visual cells—*a*, Outer segment; *i*, inner segment; *k*, cone-granule; *f*, cone-fiber; *x*, fiber apparatus. 5, Radial fiber; Müller's fiber; *k*, nucleus; *r*, pyramidal base.

There are usually three or four rod cells to one cone cell; a recent estimation of the cells, however, would place the proportion about two to one, *i.e.*, 130 million rods and 70 million cones. The rod and cone cells constitute parts of three layers, the rod and cone layer (cell bodies), the outer nuclear layer (rod and cone-fibers and nuclei) and a part of the outer reticular layer (terminal branches of the fibers).

The rod and cone cells seem to have different functions. The cone cells contain no rhodopsin and so this as well as the rod cells is unessential to sharp vision in human beings. In some animals the visual purple is said to be wanting. In birds and reptiles it is said that the cones are more numerous than the rods and in lizards there are no rods. In the owl and most nocturnal animals the cones are very few in number, poorly developed or entirely absent. The cones are said to have to do with color perception and in color blindness they are defective. The rods are concerned with light perception so that in night-blindness these elements are defective.

3. The *outer limiting membrane* is a part of the *supportive tissue* of the retina. This is *neuroglia* and comprises the *glial cells* and *fibers*. The *glial cells* are called the *sustentacular cells*, or *fibers of Müller*. These are irregular column-shaped elements that are radially placed and extend almost throughout the entire thickness of the retina. Their outer extremities fuse to form the *outer limiting membrane*, from the peripheral surface of which delicate fibrillæ extend between the rod and cone-bodies forming the *rod* and *cone sockets*. This outer limiting membrane is perforated for the bodies of the rod and cone cells. The inner extremities of the sustentacular cells fuse to form the *inner limiting membrane* the most internal layer of the retina. From these cells of Müller lateral branches are given off. These assist the glial fibers in forming the general supportive tissue of the retina. In the meshwork thus formed there are some *astrocytes* in the ganglion cell layers.

The **nuclear** or **granule layer** consists of four or five layers of nuclei that represent the nuclei of the rod and cone cells and the bulk of the fiber processes of these cells. The cone nuclei are all in a single row along the outer limiting membrane and form only about one-fourth of the thickness of the layer. The remainder is made up of the nuclei of the rod cells that are scattered throughout the inner three-fourths of this layer. Glial fibers are present as are also some of the dendritic branches of some of the small cells of the outer ganglionic layer.

5. **Henle's fiber layer** is best developed in the macular region from which area it diminishes peripherally. It is usually considered a specialized portion of the outer reticular layer but differs from it in that its fibrils are radially arranged while the others are irregular.

6. The **outer reticular,** or **molecular layer** is a meshwork of fibrils from different sources. On the one hand, the rod and cone fibers (really axones) terminate here in teloneurites; these form synapses with the telodendrites, or process that come from the cells of the outer ganglionic layer and constitutes the end of the first neuron of the visual pathway.

7. The **outer ganglionic,** or **inner nuclear layer** consists of several varieties of closely packed cells. The outermost cells are horizontally placed. They are stellate, or pyramidal cells of two sizes mainly. The dendrites of the large cells pass to the reticular layer and terminate in relation with the filaments of the rod-fibers. Those of the smaller cells end in relation with the filaments of the cone-fibers. The axones of both large and small cells pass to the inner reticular

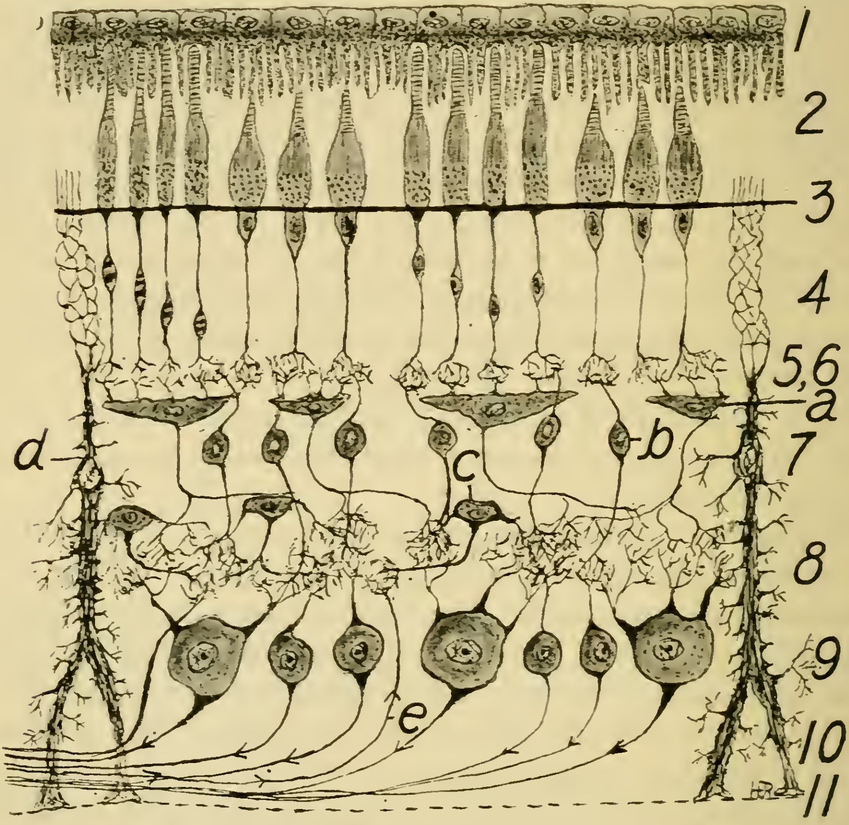


Fig. 282.—Diagram of the Layers of the Retina.

1, Layer of pigment cells; 2, rod and cone bodies; 3, inner limiting membrane; 4, (outer) nuclear layer; 5, 6, layer of Henle's fiber and outer reticular layer; 7, outer ganglionic layer (inner nuclear layer); *a*, horizontal cells; *b*, middle layer; *c*, amakrin cells; 8, inner reticular layer; 9, inner ganglionic layer; 10, layer of nerve fibers; *e*, nerve fiber from the brain terminating in the inner reticular layer in relation with the teloneurites of an anakrin cell; 11, internal limiting membrane; *d*, sustentacular (Müller) forming the limiting membranes and general supportive substance of the retina.

layer where they form synapses with the dendritic processes of the large ganglion cells. It is said that the smaller cells are of an *associative function.*

The *middle portion* of the outer ganglionic layer contains the *bipolar cells* that are the most numerous of this layer. These are placed vertically and the small amount of cytoplasm present continues internally as an axonic process that terminates in the inner reticular layer in relation with the process (dendritic) of the large ganglion cells. The peripheral processes of the oval cells are the dendrites and they terminate in telodendrites in the outer reticular layer in relation with the terminal fibrils of the rod and cone-fibers, forming synapses.

The *inner cells* are the *amakrin cells of Cajal* and these form a thin zone near the inner boundary of the ganglionic layer. These large stellate elements send their dendrites to form a part of the outer reticular layer. They were called amakrin cells because it was believed that they possessed no axones, but they do. Some of these axones pass to the inner reticular layer and terminate in relation with the terminal fibrils of axones that come from the brain through the optic nerve. Little is known about the other axones.

The nuclei of the cells of Müller lie in this layer.

8. The **inner reticular,** or **molecular layer** consists of a dense reticulum of fibrils. These fibrils represent the teloneurites of the cells of the outer ganglionic layer and of some of the axones of the fibers of the optic nerve (centrifugal) and the telodendrites of the cells of the inner ganglionic layer. These fibrils may give the layer a striated appearance.

9. The **inner ganglionic layer,** or **layer of large nerve cells** is composed of a single layer of large multipolar ganglion cells. The cell bodies are flask-shaped, spheroidal, or even stellate and their axones form the greater part of the nerve fiber layer. The dendrites pass peripherally and form a part of the inner reticular layer. In the region of the macula lutea these cells form a layer seven to eight cells deep; in the fovea centralis they are absent.

10. The **layer of nerve fibers** represents the expanded portion of the optic nerve. These fibers arise mainly from the large ganglion cells and are at first amyelinated. They converge from all parts

of the retina toward the optic nerve area, or blind spot, become myelinated and pass through the cribriform lamina. By virtue of this convergence of the fibers at the blind spot the nerve fiber layer is thickest here and forms a ridge-like elevation at this region. This layer decreases in thickness as the ora serrata is approached and at this region ceases entirely. The fibers may interlace somewhat within the layer. Some of the fibers within this layer are derived from the brain and carry impulses into the eyeball. Some of these axones terminate in relation with the axones of the amakrin cells.

11. The **inner limiting membrane** is a delicate structure formed by the fusion of the internal extremities of the cells of Müller. This limits the retina internally and is in contact with the hyaloid membrane of the vitreous humor.

The retina contains a rich capillary plexus derived from a special vessel, the *central retinal artery*. This enters the eyeball through the center of the optic nerve and within the eyeball divides into a *whorl-like* set of vessels from the center of the blind spot. *Venous channels* form the *central retinal vein* that passes out of the eyeball by the side of the artery. These vessels anastomose with some of the others that supply the eyeball.

There are three important areas in the retina: (1) the **optic nerve exit, optic papilla,** or **blind spot**; (2) the **macula lutea,** or **yellow spot,** and (3) the **ora serrata.**

1. In the **blind spot,** only the layer of nerve fibers is present. It lies about one-eight of an inch to the nasal side, and about one-tenth of an inch below the optic axis. In the center is usually a shallow depression; around the edge it is raised and forms the **papilla nervi opticæ.**

2. The **yellow spot** is not in the direct visual axis. The color is due to the presence of a diffuse yellow pigment. Its edge is raised, owing to the great thickness of the *inner ganglionic layer.* From the edge to the center, all the layers decrease and disappear, so that in the center, the **fovea centralis,** the *cones alone are present. Here vision is most acute.*

3. At the **ora serrata** all of the neural layers end abruptly, and are continued as a single layer of cuboidal or columnar cells. Beyond this point, *there is no vision.*

The light rays falling upon the retina are not transmitted to the brain by a direct route. The impressions are received by the *rods* and *cones*, which send impulses to the *outer reticular layer* (end of the first neuron); here the impulses are received by the processes of the *outer ganglionic layer*, conveyed through the bodies of the cells of that layer to the *inner reticular layer* (end of the second neuron); here they are relayed to the processes of the cells of the *inner ganglionic layer* and to its cells (cells of the third neuron) and thence to the *nerve fiber layer;* the latter makes up the optic nerve by means of which the impulses are then conveyed to various parts of the brain. The cell of the lower centers (pulvinar, corpora quadrigemina) represent the fourth neuron cells while those of the cuneus represent the fifth neurons.

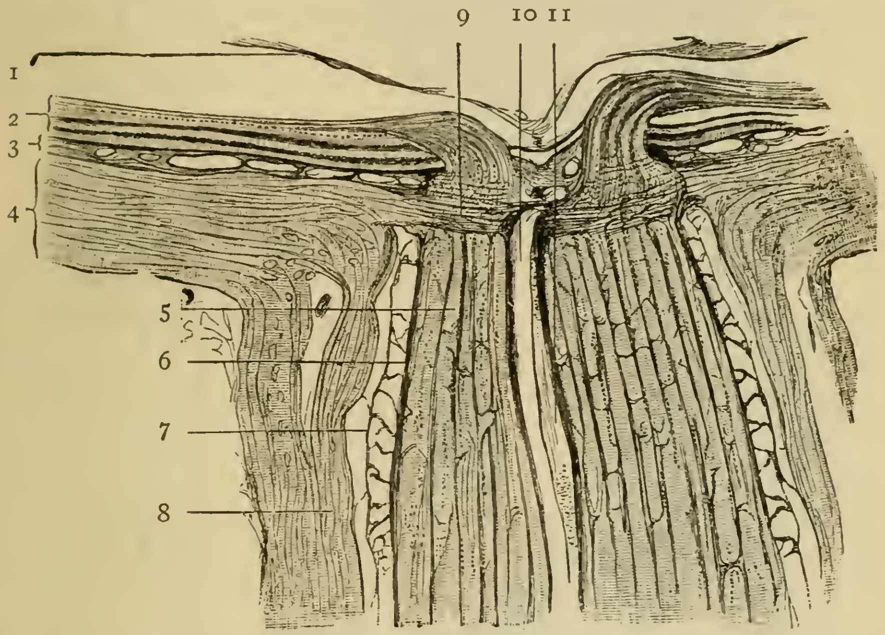


FIG. 283.—LONGITUDINAL SECTION OF THE OPTIC ENTRANCE OF A HUMAN EYE. × 15. (*Lewis and Stöhr.*)

Above the lamina cribrosa is seen the narrowing of the optic nerve, due to its loss of myelin. The central artery and vein have been for the most part cut longitudinally, but above at several points transversely. 1, Hyaloid membrane loosened; 2, retina; 3, chorioid; 4, sclera; 5, bundles of the optic nerve; 6, pial sheath; 7, arachnoidal sheath; 8, dural sheath; 9, fibers of the lamina cribrosa; 10, central artery; 11, central vein.

The **optic nerve** consists of a single bundle of nerve fibers that

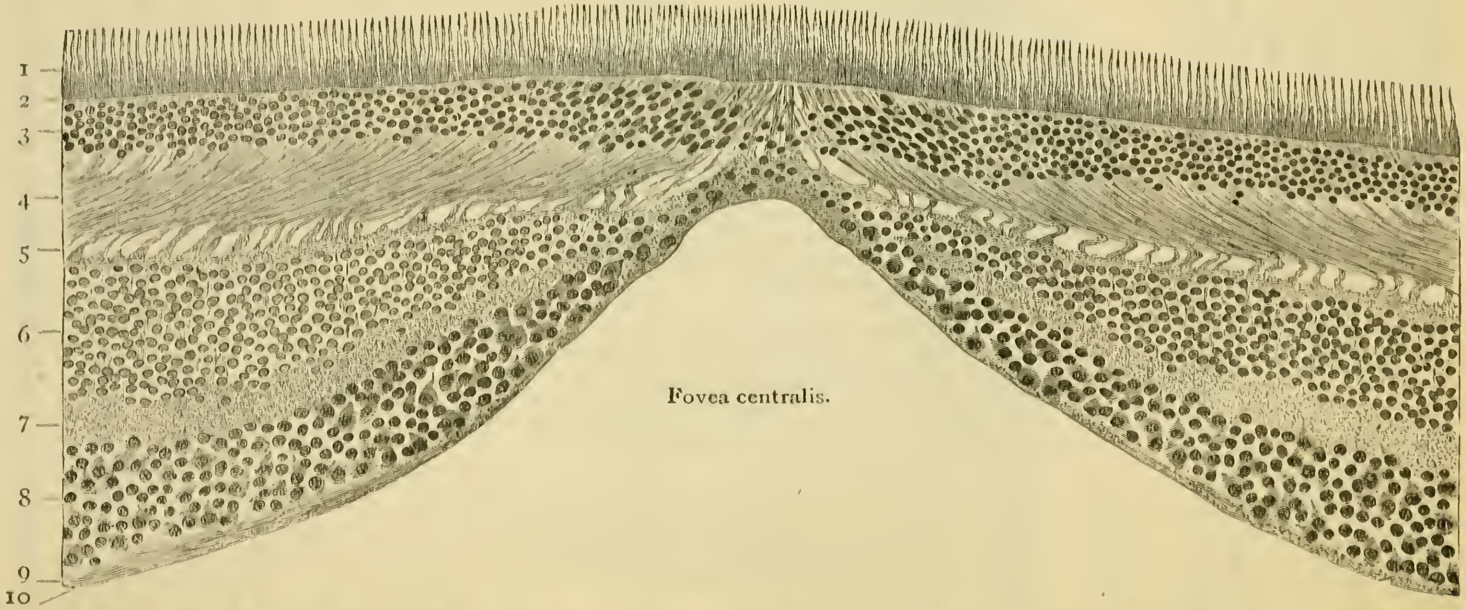


FIG. 284.—HORIZONTAL SECTION THROUGH THE MACULA AND THE FOVEA OF A MAN SIXTY YEARS OLD. × 135. (*Schaper.*) The nerve fiber layer, like all the layers, is thicker on the side toward the papilla of the optic nerve than on the opposite side; in the latter situation the nerve fibers are seen in transverse section as minute dots. The section is not through the exact center of the fovea, for there only cone cells are present; no remnants of the confluence of the inner granule and ganglion cell layers are found. 1, Cones; 2, external limiting membrane; 3, nuclei of cones; 4, Henle's fiber layer; 5, outer reticular layer; 6, inner nuclear layer; 7, inner reticular layer; 8, layer of ganglion cells; 9, nerve fiber layer; 10, internal limiting membrane.

possess no neurilemmæ. It is said to contain from 450,000 to 800,000 nerve fibers. It is surrounded by the dura, arachnoid, and pia, continued from the brain. The lymph spaces included within these, communicate with those of the eyeball. The dura and pia pass over into the sclera, but the arachnoid, as such, is lost before this occurs; as a result, the two lymph spaces between these three layers become one. The nerve fibers penetrate the sclera through the *lamina cribrosa.* As they pass through this coat, they lose the myelin sheath, so that they become amyelinated fibers when they connect with the retina.

VITREOUS BODY AND LENS

Of the **refractive media** of the eyeball, the **vitreous** and **aqueous humors** and the **lens** are yet to be described.

The **vitreous humor,** or **body,** occupies the optic cup, or **vitreous chamber.** Upon its anterior surface is a deep depression in which the posterior surface of the lens rests. This is the *patellar fossa.* This body consists of a fine limiting membrane, the **hyaloid membrane,** a delicate homogeneous structure enclosing the substance of organ, which is composed of about 98 per cent. water and 2 per cent. solid elements. The latter comprise connective tissue and wandering cells, and some fibrils. The vitreous body is jelly-like in consistency.

This structure is traversed by a small canal, called the **canal of Stilling,** or **hyaloid canal.** This extends from the optic nerve to the lens, and in intrauterine life is occupied by a branch of the retinal artery, the **hyaloid artery,** that passes to the lens.

The **aqueous humor** is practically lymph. It occupies the anterior and posterior chambers, and as a refractive medium is unimportant.

The **crystalline lens** is the most important refractive medium of the eyeball. It is a solid, biconvex body measuring about 9 to 10 mm. in its transverse dimension and from 3.5 to 4 mm. anteroposteriorly. The latter dimension varies with the amount of accommodation. In the adult it weighs about 180 milligrams and at birth about 120 milligrams. The curvature of the posterior surface is the greater but is practically fixed. The anterior curvature is chiefly the one that changes in accommodation.

The lens consists of a *capsule* within which is the *lens substance.* The *capsule* is a transparent and apparently homogeneous membrane that is about twice as thick upon the anterior surface as upon the posterior. The posterior surface is in contact with the hyaloid membrane of the vitreous humor while the anterior surface touches the posterior surface of the iris. To the capsule the fibers of the suspensory ligament are fastened.

The *lens substance* consists of the *lens cells* and *lens fibers.* The *cells* are columnar in the early childhood and gradually reduce in height as age advances so that in the elderly individuals they may be flattened elements. These cells are few in number and are found only on the anterior surface of the lens substance, just beneath the capsule; here they form a single layer of cells. Toward the equator of the lens these cells successively lengthen so that at the equator they are lens fibers.

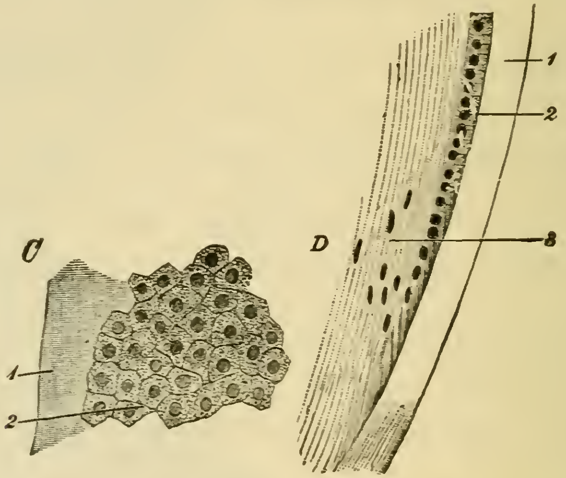


FIG. 285.—CAPSULE AND EPITHELIUM OF A LENS OF ADULT MAN. (*Lewis and Stöhr.*)

C, Tangential section. *D,* Meridional section across the equator of the lens: 1, capsule; 2, epithelium; 3, lens fibers. × 240.

The *lens fibers* are simply the elongated and modified lens cells. This change is permanent and the fibers cannot reproduce themselves. As the fibers become older the nucleus is gradually lost and the substance of the fiber seems to lessen and become hardened, forming dense tough structures. The nuclei are said to be left at the equatorial region of the lens where they form the *nuclear zone.*

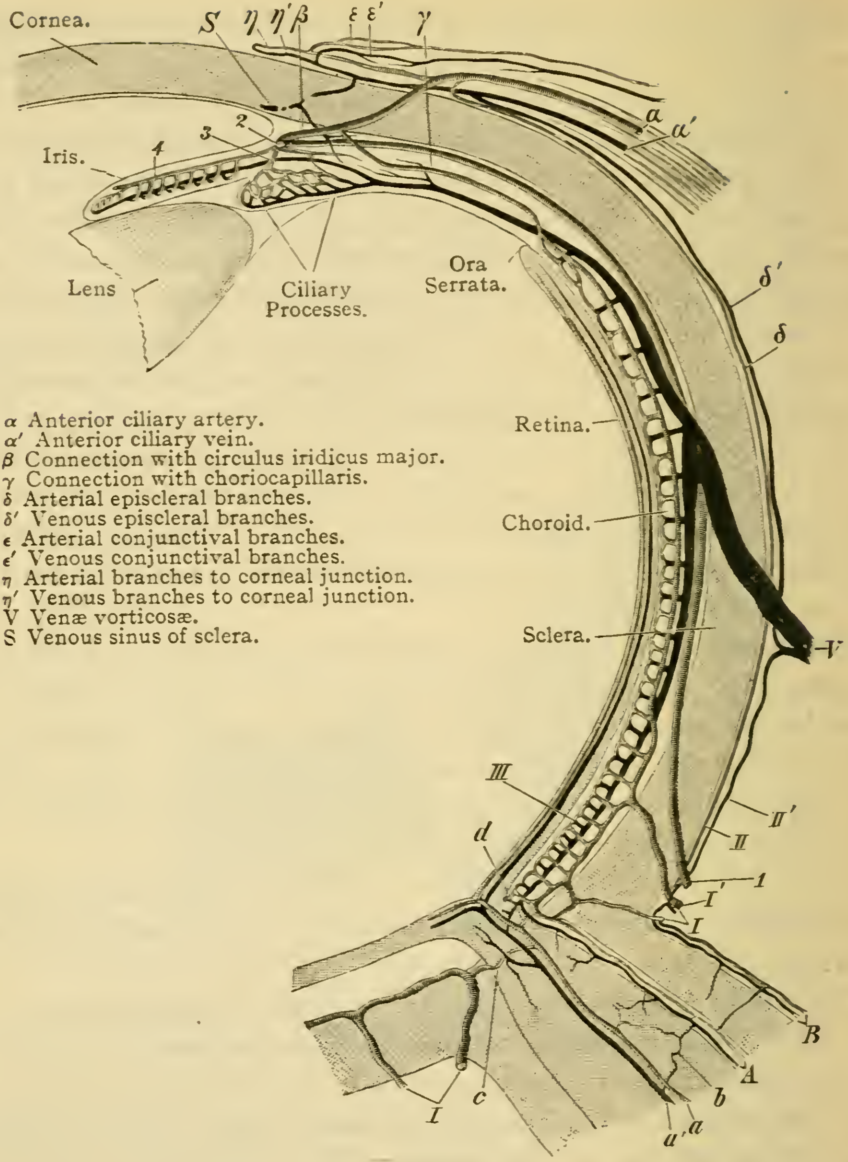
The *suspensory ligament of the lens* is really a continuation of the hyaloid membrane reinforced by a large number of fibers that pass from the anterior and posterior layers of the capsule. The fibers from the anterior layer converge in groups and are attached to depressions between the ciliary processes; those from the posterior layer have a similar course and are attached to the summits of the processes. The two layers of the ligament form a wedge-shaped area around the equator of the lens and this is known as the *canal of Petit.* This is a lymph channel and the anterior layer of the ligament is not complete, permitting communication between this space and the posterior chamber of the eyeball. The region between the ciliary processes and the margin of the lens is known as the *zone of Zinn* (*zonula ciliaris*).

The **chambers** of the eyeball are **anterior, posterior** and **vitreous** or **optic cup.** The **anterior** lies between the iris and cornea, the **posterior** between the iris and capsule and suspensory ligament of the lens, and the **vitreous** is occupied by the vitreous body. These are large lymph spaces, and are connected with one another, and with the other spaces of the eyeball.

The *circulation* of the eyeball is carried on by the **central artery of the retina,** the **long** and **short posterior** and the **anterior ciliary arteries.**

The **retinal artery** passes into the eyeball through the center of the optic nerve, and forms a *whorl* of branches upon its entrance. These vessels extend to the ora serrata. The layer of rods and cones and the macula lutea possess no blood-vessels. The arterioles are terminal and do not anastomose with one another. The blood is collected by venous stems, which form the *central vein of the retina* that has a course parallel to the artery.

The **short posterior ciliary** arteries are about twenty in number. They pierce the sclera near the exit of the optic nerve in a circle called the *circle of Zinn* and pass into the choroid. As they pass through the sclera, they give off branches that supply the posterior half of this coat. In the choroid, these vessels form the layer of


Cornea.
S
η
η′
β
ε
ε′
γ
α
α′
2
3
Iris.
4
Lens
Ciliary Processes.
Ora Serrata.
δ′
δ
Retina.
Choroid.
Sclera.
V
III
II′
II
d
1
I′
I
B
A
b
I
c
a′
a

α Anterior ciliary artery.
α′ Anterior ciliary vein.
β Connection with circulus iridicus major.
γ Connection with choriocapillaris.
δ Arterial episcleral branches.
δ′ Venous episcleral branches.
ε Arterial conjunctival branches.
ε′ Venous conjunctival branches.
η Arterial branches to corneal junction.
η′ Venous branches to corneal junction.
V Venæ vorticosæ.
S Venous sinus of sclera.

FIG. 286.—VESSELS OF THE EYE.

External tunic, stippled; middle tunic, white; internal tunic and optic nerve, stippled criss-cross; arteries, light; veins, dark.

Central vessels of retina; *a*, artery; *a′*, vein; *b*, *c*, *d*, anastomoses with vessels of sheath, short posterior ciliary arteries and choroidal vessels, respectively.

A, inner, *B*, outer sheath vessels; 1, short posterior ciliary artery; *I′*, vein; *II*, episcleral artery; *II′*, veins; *III*, capillaries of choriocapillaris; 1, long posterior ciliary artery; 2, circulus iridicus major; 3, branches to ciliary body; 4, to iris. (*Stöhr's Histology.*)

large vessels and the *choriocapillaris*. Their branches anastomose with branches of all others, including those of the central artery of the retina.

The **long posterior ciliary** arteries pierce the sclera near the optic nerve, and pass to the ciliary region between the choroid and sclera. At the base of the iris, they form a circle of vessels, the **circulus arteriosus iridicus major,** which sends branches to the ciliary processes, the choroid and the iris; the latter branches pass to the pupillary region, where they form the **circulus iridicus minor.**

The **anterior ciliary** arteries are derived from the vessels of the recti muscles. These penetrate the sclera near the corneoscleral junction about 2 mm. from the margin of the cornea. Their branches nourish the anterior half of the sclera, the conjunctiva, the ciliary muscle, and the anterior half of the choroid; they connect with the circulus iridicus major, and form a network of capillaries at the corneoscleral junction. Around the optic nerve, there is some anastomosis between the branches of the ciliary arteries.

Most of the blood is returned by the **venæ vorticosæ**, which are four to six in number. These run a course entirely different from that of the arteries. Each is formed by a *whorl* of veins, and passes through the sclera to empty into the ophthalmic veins. The blood from the anterior ciliary arteries is carried by the anterior ciliary veins that run parallel to the arteries. These also receive the blood from the episcleral spaces.

The **lymphatics** are extensive, and form a series of intercommunicating spaces.

Anteriorly, the spaces in the cornea communicate with those of the sclera, and with the canal of Schlemm and the anterior chamber, by means of the spaces of Fontana.

The *anterior chamber* communicates with the posterior chamber, and through this, with the canal of Petit.

Posteriorly, the lymphatics of the optic nerve communicate with the subarachnoidean space, on the one hand, and the hyaloid canal and perivascular spaces of the retina, on the other.

The *space of Tenon* lies external to the sclera, and receives lymph from the subscleral space, directly, and by way of the channels around the venæ vorticosæ; the lymph is sent to the spaces around the optic nerve. The latter communicate with those of the central nerve system.

Some describe the *lymphatic spaces* under *two sets*, *anterior* and *posterior*. The *anterior* include the canal of Petit, the lymph spaces of the ciliary region and iris, the spaces of Fontana, anterior and posterior chambers and the corneal spaces. The *posterior set* includes the spaces of the vitreous humor, retina the subscleral, or suprachoroidal spaces, the perivascular spaces of retina and choroid, the capsule of Tenon and the subarachnoid and subdural spaces of the brain continued along the optic nerve to the eyeball. These communicate freely with each other through the zonule of Zinn region and through the lymph channels around the vessels.

The *nerves*, *long* and *short ciliary*, supply the choroid and pass between it and the sclera; at the ciliary body, they form the *ciliary ganglion plexus*, that supplies the ciliary muscle, iris and cornea and vessels. Those of the iris form a circular plexus. The nerves of the cornea have been considered.

THE APPENDAGES OF THE EYEBALL

The **appendages** are the **eyelids, conjunctiva** and the **caruncle.** The **eyelid** consists of a double fold of skin, the under surface of which has become modified to form a **mucous membrane.** This is the **conjunctiva**, which is composed of *stratified columnar* cells that rest upon a *basement membrane* and *tunica propria.* These cells are four or five layers in number and the basal elements are the smallest. The surface cells are somewhat pyramidal in form with the bases forming the surface and the apices buried among the other cells. These cells seem to be distensible. Among the epithelial cells some goblet cells are seen. The tunica propria is thin and firmly attached to the eyelid. Over its greater extent, the conjunctiva is smooth, but toward the region opposite to the free edge, folds are formed. There may be some small tubuloalveolar glands in the tunica propria here. They are the *glands of Waldeyer.*

Beneath the tunica propria is found a dense plate of white fibrous tissue called the **tarsal plate** (*incorrectly called cartilage*). This is wedge-shaped, with its thicker edge at the margin of the lid. It extends a little over one-half the height of the lid, and at its end an **accessory tear gland** is found, the gland **of Krause.** It contains a number of *compound racemose glands*, the ducts of which open

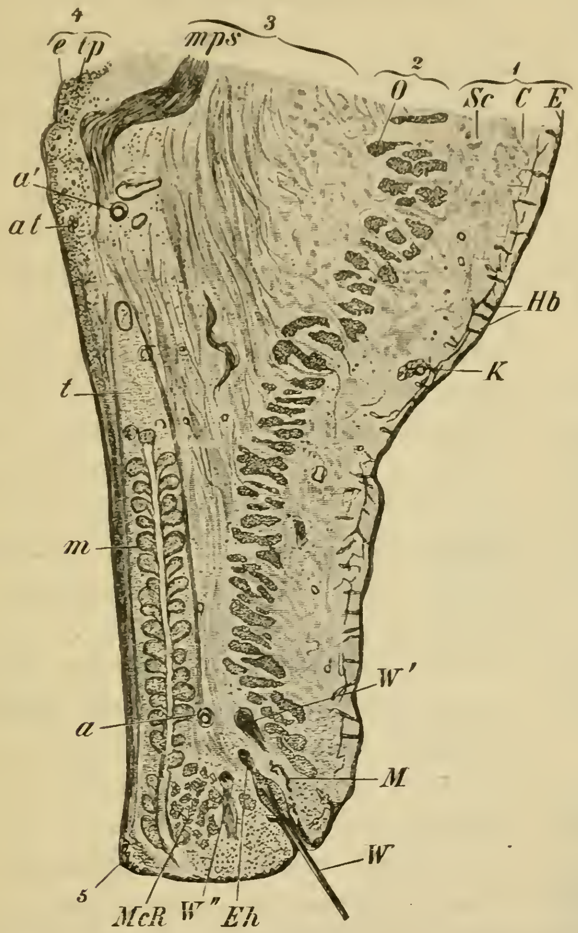


Fig. 287.—Sagittal Section of Eyelid of a Child Six Months Old. (*Stöhr's Histology.*)

1. Skin: *E*, Epidermis; *C*, derma; *Sc*, subcutaneous tissue; *Hb*, lanugo hairs; *K*, sweat-glands; *W*, eyelash; *Eh*, developing lash; *W'*, *W''*, portions of follicle of eyelashes; *M*, portion of a ciliary gland. 2, Orbicularis palpebrarum muscle: *O*, transverse section of same; *McR*, tarsal muscle. 3, tendon of levator palpebrarum superior; *mps*, superior levator muscle; 4, conjunctival portion; *e*, epithelium; *tp*, tunica propria; *at*, accessory tear gland; *t*, tarsus; *m*, tarsal gland (Meibomian); *a*, arcus tarseus externus; 5, margin of eyelid.

upon the free margin. These are the **Meibomian,** or **tarsal glands,** and number about thirty in the upper, and about twenty in the lower lid. They resemble sebaceous glands in structure and the alveoli are filled with cells that are in varying stages of fatty change; the ducts are lined by stratified squamous cells. At the margin of the lid muscles fibers *marginal muscles* are seen behind the ducts. These glands secrete an oily substance that lubricates the edges of the lids, prevents them from uniting, and ordinarily keeps the tears from overflowing.

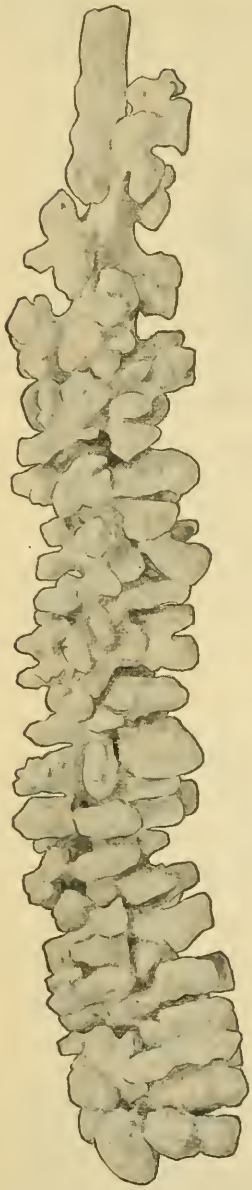


FIG. 288.—MEIBOMIAN OR TARSAL GLAND, RECONSTRUCTED AFTER BORN'S WAX-PLATE METHOD. ×20. (*Böhm, Davidoff and Huber*).

Between the tarsal plate and the skin surface, is found the **subcutaneous fibrous tissue**. In this layer is the muscle of the eyelid, which is chiefly of the voluntary variety, although some smooth muscle is present. This smooth muscle tissue constitutes the Superior and Inferior tarsal muscles. Some voluntary muscle fibers are found between the cilia and Meibomian gland; these constitute the *musculus ciliaris Riolani*. In the tarsal connective tissue are found smooth muscle fibers that are attached to the proximal end of the tarsal plates; these constitute the **lid-muscle of Müller**. *Diffuse lymphoid tissue* and even solitary nodules may be seen in varying quantities in the tunica propria.

The **skin** covers the outer surface. Its structure is the same as in other places, and it contains many sebaceous and sweat-glands and fine hairs. Pigmented cells are found in the corium. Very little fat is found in the loose subcutaneous tissue.

At the edge of the lid, are seen two rows of heavy hairs, the **cilia,** or **eyelashes.** They pass deeply into the corium, and last about four months. Between the cilia and the ducts of the Meibomian glands, are some *coiled tubular* structures called the **glands of Moll.** These are *ceruminous glands*, and resemble those of the external ear. Their ducts at times are seen to open into the follicles of the cilia.

The skin at the conjunctival margin forms an acute angle, while above the ciliary region the angle is obtuse. This serves to distinguish these two margins.

The **conjunctiva** lines the internal surfaces of the eyelids, and is then reflected over the eyeball from the insertion of the muscles to the cornea. It is loosely attached to the eyeball. Here the stratified cells alone continue upon this organ. It consists of peculiar *stratified columnar cells*, *basement membrane* and *tunica propria*. In the latter lymphoid tissue is often present in abundance. That part of the conjunctiva which is reflected from the eyelids to the eyeball is called the *fornix conjunctivæ*. Here the conjunctiva is loose, attached to the underlying tissues as well as to the eyeball. This laxity and the presence of the orbital fat permit the great freedom of motion of the eyeball.

At the inner angle, or **canthus**, of the lids is seen, in lower animals, a **third eyelid**. This is called the **plica semilunaris**, or **membrana nictitans**. In lower forms, a *distinct tarsal plate is present*, which is seldom present in man. Here it is usually a small fold, covered by *stratified squamous* cells, in which some glands may be found.

The **caruncle** is a little patch of skin at the inner canthus. It contains hair follicles, sweat-glands, adipose and muscle tissues within its corium, and is covered by *stratified squamous* cells. A little voluntary striated and some smooth muscle tissues are present.

Within the eyelid, *two arterial arches* are formed, one at the proximal edge of the tarsus, the *external*, and the other at the edge of the lid, the *internal*. These arches are produced by the vessels coming from the inner and outer canthi. The smaller branches pass to the glands and conjunctiva of the lid, where they form delicate plexuses.

The *lymphatics* form a close, delicate plexus beneath the conjunctiva, and a loose set at the upper margin of the lid, that communicate with each other. The branches of the latter possess valves.

The *nerves* give off branches to the muscles and skin, and then form a plexus beneath the conjunctiva. The latter supplies the glands, cilia and conjunctiva, forming, in the latter, a subepithelial plexus and sensor organs, such as **conjunctival corpuscles** and **bulbs.**

THE LACRIMAL APPARATUS

The **lacrimal apparatus** consists of the **lacrimal gland,** the **canaliculi,** the **lacrimal sac** and the **nasolacrimal duct.**

The **lacrimal gland** is a *compound tubular* organ of a serous character. Like the mammary gland, it is a *multiple compound gland,* as it is composed of six or seven individual glands merely bound into one mass. Each has its own duct that opens upon the conjunctival surface.

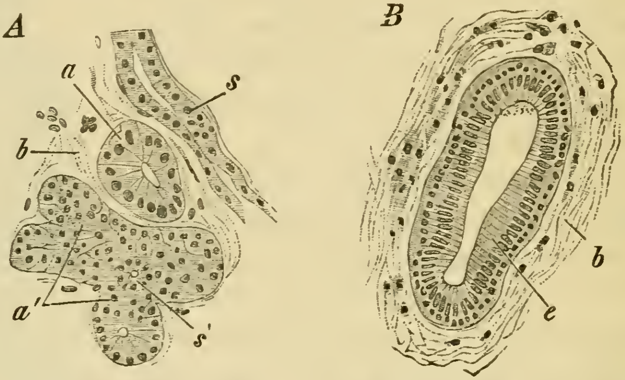


FIG. 289.—FROM A SECTION OF A HUMAN LACRIMAL GLAND. × 420. (*Lewis and Stöhr.*)

A, Gland body: *a*, Tubule cut across; *a'*, group of tubules cut obliquely; *s*, intercalated tubule; *s'*, intercalated tubule in cross section; *b*, connective tissue. *B*, Cross-section of an excretory duct: *e*, Two-rowed cylindrical epithelium; *b*, connective tissue.

Each **gland** is covered by a delicate **capsule** of white fibrous tissue that divides it into **lobes** and **lobules.** The **lobules** consist of the **tubular acini,** which are lined by *simple columnar*, or *cuboidal cells.* The cytoplasm of these is granular, and the nuclei have a basal position. The cells that have just discharged their secretion are small and the cytoplasm is granular. During the resting stage the cell becomes swollen and the cytoplasm is usually clear. The nucleus has a basal position. With the discharge of the secretion the cells are again smaller and more granular. These cells rest upon a *basement membrane,* containing *basket cells,* which is supported by interstitial connective tissue of a fibroelastic nature. The intralobular and interlobular ducts are lined by simple columnar cells; the main ducts are lined with stratified columnar cells.

The *blood-vessels* are numerous and form close capillary plexuses around the tubules.

The *nerves* form a subepithelial plexus, but the exact mode of ending is not known.

Each **canaliculus** has a lining of *stratified squamous cells* that rest upon the *tunica propria* and fibro-elastic layer. Outside of the tunica propria is seen some *voluntary striated muscle,* chiefly longitudinally arranged.

The opening of the canaliculus is called the *punctum,* and at this point some of the muscle fibers are circularly disposed, forming a *sphincter* muscle.

The **sac** and **duct** are lined by *stratified columnar cells.* In the *tunica propria,* considerable diffuse lymphoid tissue is found. Occasionally, in the lower end of the duct, *ciliated epithelial cells* are present.

Within the orbit, the eyeball is surrounded by a serous membrane called the *capsule of Tenon.* The space enclosed is the *space of Tenon,* or the *episcleral lymph space.* This space aids in the movement of the eyeball.

CHAPTER XIX

THE EAR

The **ear** (*orgonan auditus*) is made up of three parts, the **external, middle** and **internal.**

The **external ear** receives the sound waves and conducts them to the **middle ear.** The vibrations of the **drum** are carried across the middle ear and conducted into the **internal ear,** where they are translated into the proper nerve impulses and conveyed to the temporal lobe of the cerebrum.

The **external ear** consists of the **pinna** and a short **canal,** the **external auditory canal.**

The **pinna,** or **auricle** is covered upon both surfaces by skin and in the center is a mass of elastic cartilage. It is very irregular but is adapted to catch the sound waves. The skin is in no way different from that of the general body surface and possesses fine hairs and some sweat glands. Connected with the small hairs are large sebaceous glands. The irregular mass of elastic cartilage occupies the pinna proper and does not extend into the *lobule.* The *latter* is the lower, soft portion and this is very vascular. The *cartilage* is surrounded by a perichondrium to which the derma and the intrinsic aural muscles are attached. The firm attachment of the derma prevents movements of the cartilage. The *matrix* consists of chiefly elastic tissue that forms a network in which are groups of large cartilage cells imbedded in a small amount of hyalin substance. The elastic tissue is less prominent in the child than in the adult. In the child at birth this reticulum responds readily to the reticulum stain and not to the elastica stain. Adipose tissue is not present in the pinna.

The **external auditory canal** consists of *outer cartilaginous* and *inner bony portions.* Both portions are lined by skin which is an extension of that of the pinna. This consists of *stratified squamous* *cells* that rest upon a *basement membrane* and *derma*. In the skin of the outer part there are numerous, large, stiff hairs, sebaceous glands and some coiled tubular glands that secrete the *ear wax*. These *ceruminous glands* are analogous in structure to the sweat glands; the functionating cells, however, contain some fine brownish pigment granules. The *derma* is attached to the tube-like continuation of the elastic cartilage of the pinna.

The skin of the inner part is thinner and is attached to the bony wall of the canal. Some very fine hairs may be present in the outer part but near the tympanic membrane part of the canal hairs and glands are absent. The uppermost layers, at least, of the external auditory canal move constantly from within, outward. By this means the cerumen is ordinarily moved to the outlet.

THE MIDDLE EAR

The **middle ear** comprises the **tympanum, membrana tympani, auditory ossicles** and **auditory tube.**

The **tympanum** (*cavum tympani*) consists of the *tympanic cavity proper*, the *attic* and here may be added the *mastoid cells*. The **tympanic cavity proper,** or **atrium** is a narrow space that is nearly parallel to the sagittal plane of the body. It measures about 15 mm. in height and length, but the distance between the lateral and medial walls varies; at the top it is 6 mm., in the middle 2 mm., at the bottom 4 mm. About the level of the tympanic membrane the tympanic cavity forms a recess called the *attic*, or *epitympanum*. This contains most of the incus and half of the handle of the malleus and communicates with the mastoid antrum. From the lower part of the anterior wall the auditory tube extends to the pharynx. Upon the medial wall are *two openings*, in dried specimens. The *upper* is oval in shape and is called the *fenestra vestibuli*. This measures about 3 mm. horizontally and 1.5 mm. vertically. In the fresh condition this opening is blocked by the foot of the stapes and its annular ligament. Beneath this is the *second opening* that is circular in outline. This is the *fenestra cochleæ* and in the fresh condition it is closed by the *membrana tympani secundaria*.

The *tympanic antrum* is about 8 mm. by 10 mm. and connects the epitympanum with the mastoid cells. The *mastoid cells* vary in number and size and may extend almost to the tip of the mastoid process. They are usually quite numerous in the adult and are said not to be developed until the sixth year.

The *tympanic cavity* and its extensions are lined with a *mucous membrane* that is continuous with that of the pharynx through the auditory tube. The *cells* are of the pseudostratified ciliated variety, chiefly, though parts of the cavity may possess nonciliated cells and even stratified squamous cells. Upon the ossicles, ligaments and tympanic membrane the cells are nonciliated. These cells rest upon a delicate *basement membrane* and *fibroelasiic tunica propria*. The latter is attached to the periosteum of the bony boundaries very firmly. Small mucous glands are found in the tunica propria and diffuse lymphoid tissue may also be present. The *antrum* and

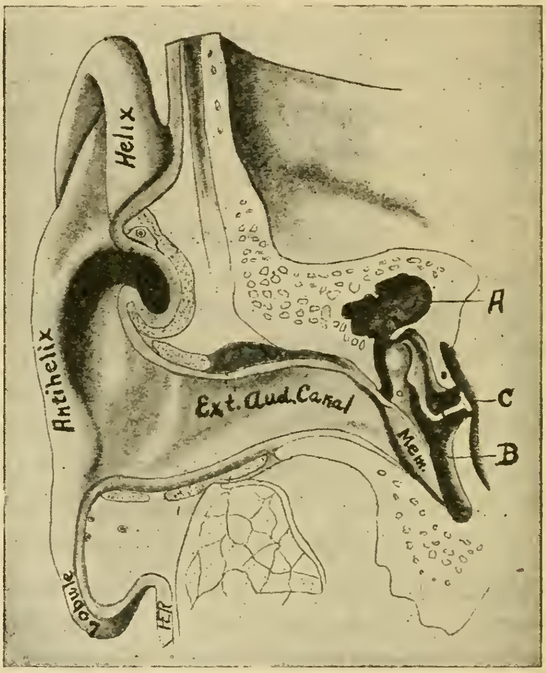


FIG. 290.—VERTICAL SECTION THROUGH THE EXTERNAL AUDITORY CANAL AND TYMPANUM.

A, Epitympanic recess; *B*, tympanum; *C*, fenestra ovalis closed by foot of the stapes; *Mem.*, tympanic membrane. (*Radasch*, "*Manual of Anatomy*.")

mastoid cells are lined by low polygonal or flattened epithelial cells. The tunica propria throughout is quite vascular.

The **tympanic membrane** is an elliptical, disc-like membrane that slopes downward, medially and backward. It is about 10 mm. in its vertical dimension and about 9 mm. from side to side. It separates the middle ear from the external auditory canal. Its circumference is thickened by the circularly directed fibers of the *annulus fibrocartilagineus*, that attaches it to the circumference of the medial end of the external auditory canal. The handle of the malleus is attached to its medial surface and above this attachment and prominence the membrane is flaccid (*pars flaccida*). The bulk of the membrane is tense (*pars tensa*). The central part of the membrane is drawn slightly inward by the attached handle of the malleus and this part of the membrane is called the *umbo*. Externally, it is covered by *stratified squamous* cells continued from the skin. In this location, the stratum corneum is nucleated, and the corium is thin, except in the region of the handle of the malleus. The *middle* portion consists of white fibrous tissues arranged as *radial*, or *external*, and *circular*, or *internal* fibers.

The *former* becomes thinner toward the center of the tympanum and disappears entirely. The *circular* fibers are more numerous externally, and become thinner toward the handle of the malleus, where they disappear. Between these two layers is a small amount of loose connective tissue. *Peripherally*, the fibrous layer becomes thickened to form the *annulus fibrosus*. The *internal* surface is covered by *simple squamous*, or *columnar* cells that rest upon a *basement membrane*. In the flaccid area of the drum, the middle layer is absent, so that the internal and external layers touch each other.

The **ear bones** are the **malleus, incus** and **stapes.** These are small masses of osseous tissue, by means of which the sound waves are transmitted from the drum to the internal ear. In the thickest portions they possess Haversian systems. Their articular surfaces are covered with hyalin cartilage. The stapes alone possesses a marrow cavity.

The *malleus* is the largest having a length of 8 to 9 mm. The main parts are the *head* and *handle*. By means of the former it articulates with the incus and by means of the *latter* it is attached to the tympanic membrane. The *incus* is next in size and means of the *body;* it articulates with the head of the malleus and by means of the *long process* it articulates with the stapes. The *stapes* is the smallest and most delicate of the ossicles. Its *head* articulates with the long process of the incus and its *foot,* or *base* rests in the fenestra vestibuli, to the boundaries of which it is attached by means of the annular ligament.

The **muscles** of the middle ear are the *stapedius* and *tensor tympani.* The *stapedius* lies entirely within the tympanic cavity and is *inserted* into the neck of the stapes. By the contraction of this muscle the anterior end of the base is tilted laterally and the posterior end medially, compressing the lymph within the vestibule. It is the smallest muscle in the body. The *tensor tympani muscle* comes into the tympanic cavity through a special canal and is *inserted* upon the medial edge of the anterior surface of the handle of the malleus in such a manner that when the muscle contracts the handle is drawn medially and the membrane is made tense.

The **auditory tube,** or better *pharyngotympanic tube,* extends from the lower part of the anterior wall of the tympanic cavity to the pharynx. It is about 36 mm. in length and is directed downward at an angle of about 30° to 40° to the horizontal plane and forward and medially at an angle of about 45° to the sagittal plane. It opens in the lateral wall of the nasopharynx.

The *first part,* about 12 mm. is called the *bony portion* as the tunica propria is attached to the periosteum of the bony boundary. The *medial two-thirds,* about 24 mm. is called the *cartilaginous portion* because outside of the tunica propris there is a ʃ-shaped mass of elastic cartilage. At the pharyngeal extremity the cartilage bulges the pharyngeal mucosa in a hook-like manner and this peculiar ridge is called the *torus tubarius.*

The **osseous** portion of the **auditory tube** is lined by a thin mucous membrane that is closely adherent to the periosteum. The lining cells are *pseudo-stratified ciliated* elements. Glands are absent. In the **cartilaginous** portion, the mucosa is thicker, and is lined by *stratified ciliated cells,* among which there are a large number of goblet cells. In the tunica propria, mucous glands and diffuse lymphoid tissue are seen, and the latter may be formed into solitary nodules near the pharyngeal end. These constitute the *tubal tonsils.*

The **membrane** closing the **fenestra rotunda** that leads to the internal ear (to the cochlear duct) consists of connective tissue. Its middle ear surface is covered by *nonciliated cells*, while that which lies in the internal ear is covered by *endothelial cells.* The base of the stapes with the annular ligament that attaches it to the edge of the foramen, completely occludes the fenestra ovalis, that leads to the vestibule.

The *blood supply* to the tympanic membrane is important. Its external surface is supplied by capillaries derived from the vessels of the external canal, while the inner surface receives vessels from those of the middle ear. The mucosa of the auditory tube receives blood from both the middle ear and pharyngeal vessels.

Lymphatic vessels follow those of the circulatory system. Those of the external surface of the membrana tympani empty into those of the external canal, while those of the inner surface empty into those of the tympanum. The latter lie in the deeper portions of the tunica propria, and at intervals possess dilatations.

The *nerves* of the external surface of the tympanic membrane are derived from the auriculotemporal and the auricular branches of the vagus. Both form a close plexus. This supplies the external surface by a subepithelial plexus. The inner surface is supplied by the tympanic plexus, which sends branches to the epithelial layer. Occasionally, minute ganglia are present. The auditory tube receives fibers from the tympanic, as well as from the pharyngeal plexuses.

THE INTERNAL EAR

The **internal ear,** or **labyrinth,** consists of two main divisions, the **osseous labyrinth** and the **membranous labyrinth**. The **osseous labyrinth** comprises the **vestibule, semicircular canals** and the **cochlea.** The **membranous labyrinth** consists of the **sacculus, utriculus, semicircular canals** and the **cochlear duct.**

The **labyrinth** consists of the **osseous** and **membranous** portions, which are separated from each other by a lymph space. The

bony labyrinth surrounds the **membranous** portion, and is separated from it by the **perilymph**. Within the membranous part is the **endolymph**.

SACCULUS AND UTRICULUS

The **vestibule** lies between the semicircular canals behind, and the cochea, in front. It is about 6 mm. anteroposteriorly, from 4 to 5 mm. from above downward and 3 mm. from without inward. Upon its lateral wall is seen the *fenestra vestibuli* that is closed by the base of the stapes and its ligament. It lodges the membranous sacculus and utriculus.

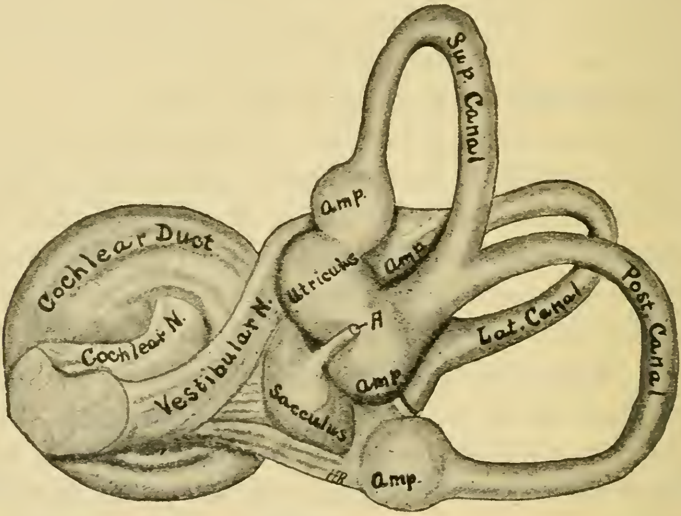


Fig. 291.—Isolated Membranous Labyrinth of the Right Side. *A*, Ductus endolymphaticus. (*Radasch*, "*Manual of Anatomy*.")

The bony walls of the vestibule are covered by periosteum, which is lined by a layer of endothelial cells continued over the trabeculæ, that extend from the periosteum to the membranous labyrinth. From this point the endothelium continues over the external surface of the membranous labyrinth.

The **sacculus** and **utriculus** are two membranous sacs of unequal size, that occupy the vestibule and do not communicate with each other directly, but with the **ductus endolmyphaticus** by two small canals. The **sacculus** is the smaller, and lies anterior to and below the utriculus. It measures about 2 by 3 mm. and is ovoid in form. The **utriculus** is connected with the ampullæ of the superior and lateral semicircular canals, while the **sacculus** communicates with the cochlear duct of the membranous labyrinth by means of the **ductus reuniens.**

The walls of the membranous saccule and utricle are composed of bundles of white fibrous tissue arranged into two layers of variable thickness, 5 to 15 microns. The thickest portions are where the nerve fibers leave the maculæ acusticæ and maculæ cribrosæ. The cells lining these vesicles consist of *simple polygonal* epithelium, 3 to 4 microns in height, except over the **maculæ acusticæ,** where they are of the **neuro-epithelial** variety. Upon approaching these areas, the polygonal change to *cuboidal* and become progressively higher until a height of 30 microns is reached. These cells are of two varieties, **sustentacular,** or **supportive,** and **special, neuro-epithelial,** or **hair-cells.**

The **sustentacular** cells are very long, irregular columns, the basal portions of which are branched. The large nuclei, located at various levels in the inner half of the cell, produce a bulging of the cell-body. The granular cytoplasm possesses *pigment granules* of a yellowish color.

The **special,** or **hair-cells,** are also columnar, but not as long as the preceding, and extend through only one-half of that layer. The basal portion of these cells is broad, and contains large round nucleus; the basal part is continued between the sustentacular cells toward the basement membrane for a variable distance and usually ends in a small knob. In the epithelial layer the terminal fibrils of the vestibular nerve form a plexus and the fibrils of this plexus terminate around these extensions of the hair cells. The distal end is rounded and possesses a cuticular border, the **cupola,** from which projects a **conical cilium** 20 microns long. This extends into the endolymph. Closer examination shows that the cilium consists of many fine hairs. The cytoplasm of these cells is granular and contains a yellowish pigment.

The **otoliths,** or **otoconia** are small, prismatic calcium carbonate crystals, 1 to 15 microns long, occuring in the vesicles, and imbedded in a gelatinous substance, the *otolith membrane,* that covers the neuro-epithelial cells. This *otolith membrane* contains many of these prisms.

The **ductus endolymphaticus** and its dilated extremity, the **sacculus**, have the same structure as saccule and utricle.

A *plexus of nerve fibers* is found beneath the neuro-epithelium. The fibers extend into the epithelial layer, and as they pierce the basement membrane, the myelin sheath blends therewith, and leaves the dendrite free. These latter form fibrillæ that are terminate in relation with the neuro-epithelial (hair) cells; some pass higher between the supportive cells.

In these areas, the *capillary plexuses* are especially numerous.

THE SEMICIRCULAR CANALS

The **osseous semicircular canals** are behind and above the vestibule. They are *three* in number and are called *superior*, *lateral* and *posterior*. Each forms about two-thirds of a circle and is about 1.0 to 1.5 mm. in diameter. One extremity of each is dilated and this dilation is an ampulla that is about 2 mm. in diameter. These canals communicate with the vestibule by five openings. The *superior canal* is vertical and is placed transversely to the long axis of the petrous portion of the temporal bone. Its length is about 18 mm. The *lateral canal* is placed almost horizontally and measures 12 to 15 mm. in length. The *posterior canal* is 20 mm. in length. The opposite lateral canals lie in the same plane while the superior canal of one ear is parallel to the posterior canal of the other ear.

The **membranous semicircular canals** are united to the periosteum by *trabeculæ*, as in the preceding, and the endothelial cells pursue the same course in the lymph space. The epithelium resembles that of the saccule and utricle, being polygonal, but slightly larger, varying from 12 to 16 microns. Specialized areas, **cristæ acusticæ**, are found in the floor of the **ampullæ** (dilated portion at the end of each canal). Here the thickened fibrous wall forms the **transverse septum.** The specialized areas resemble those of the saccule and utricle. The hairs of the neuro-epithelial cells are unusually long, some reaching to the middle of the lumen. They are called the **auditory hairs**, and arise from the **cupola** of the cells.

The *nerve* fibers pass to the thick transverse septum, and form a plexus from which finer fibers follow the same course as in the saccule and utricle.

The *blood-vessels* are distributed in the same manner.

THE COCHLEA

The **cochlea** represents a tapering tube of 20 to 30 mm. length spirally wound for about two and three-quarters turns about a vertical bony axis, the *modiolus*. The broad portion is the base that measures about 9 mm. across and is in relation with the inferior fossula of the internal auditory meatus. The end of the coil is the apex, or *cupola;* it is about 5 mm. above the base and 2 mm. above the modiolus. The basal end of the tube is 2 mm. in diameter. The *modiolus*, or *axis* is a conical mass about 3 mm. high and is pierced by many foramina for the transmission of nerve fibers. Upon the tube side the modiolus sends out a bony shelf that extends about halfway across the tube and is called the *lamina spiralis* (*ossea*). The division of the tube is completed by the *basilar membrane* that extends from the spiral lamina to the lateral wall of the osseous tube. As a result of these shelves two passageways are formed, the *upper* the *scala vestibuli* and the *lower* the *scala tympani*. At the modiolus edge of the spiral lamina there is a canal that extends the length of the spiral shelf and in this spiral canal the *ganglion of Corti* (*ganglion spirale*) is lodged. The spiral lamina and the basilar membrane extend to within a short distance of the end of the cochlear tube and at this point the two scala communicate with each other. This communication is called the *helicotrema*. Both contain *perilymph*.

The **ductus cochlearis,** or **scala media,** is a delicate, triangular, membranous canal that lies in the **scala vestibuli;** its outer basal angle is attached, *externally*, to the outer wall, and the inner angle, *internally*, to the lamina spiralis. It contains the endolymph, and has an important epithelial lining. The **basilar membrane** separates it from the **scala tympani,** and the **membrane of Reissner** from the **scala vestibuli.** The *latter* membrane is quite thin, about 3 microns, and extends from the lamina spiralis (internal to the crista) to the bony wall of the scala vestibuli at an angle of about 45°. Upon its vestibular wall, it is covered by a layer of *pigmented endothelial cells* which rest upon the middle connective tissue layer, in which capillaries are found. The epithelial lining of its inner surface consists of a single layer of *polygonal cells.* The **outer wall** of the scala media, for about two-thirds of its distance from the upper angle, is covered by *cuboidal cells,* within which there are quite a number of capillaries, a *very unusual condition.* This is the **stria vascularis.**

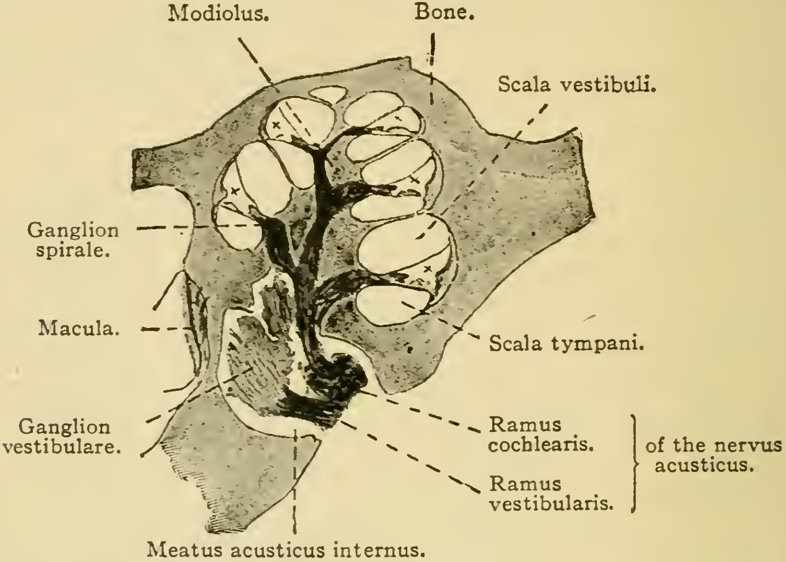

Modiolus.
Bone.
Scala vestibuli.
Ganglion spirale.
Macula.
Scala tympani.
Ganglion vestibulare.
Ramus cochlearis.
Ramus vestibularis.
of the nervus acusticus.
Meatus acusticus internus.

FIG. 292.—HORIZONTAL SECTION OF THE COCHLEA OF A KITTEN. × 8. (*Stöhr's Histology.*)

The winding ductus cochlearis, x, crossed the plane of section five times. Above it in every case is the *scala vestibuli,* and below it is the *scala tympani.*

At the lower margin of the latter is a small projection, the **prominentia spiralis;** this, with the lower part of the outer wall, is covered by flattened cells that become columnar as the basilar membrane is reached. The tissue external to these cells is quite thick, and extends over the vestibular wall above the attachment of Reissner's membrane, and below the attachment of the basilar membrane. This is the **ligamentum spirale.** At the attachment of the basilar membrane this ligament forms a projection called the **crista basilaris.**

The **floor** of the ductus cochlearis (tympanic side) consists of the **basilar membrane** that unites the **spiral prominence** to the spiral lamina; this is completed by the **limbus** that extends from the end of the spiral lamina to the attachment of Reissner's membrane.

The *outer* portion of the **limbus** is thicker near the membrane, due to an increase in the periosteum. This portion contains clefts and depressions that deepen toward the inner half, at which point

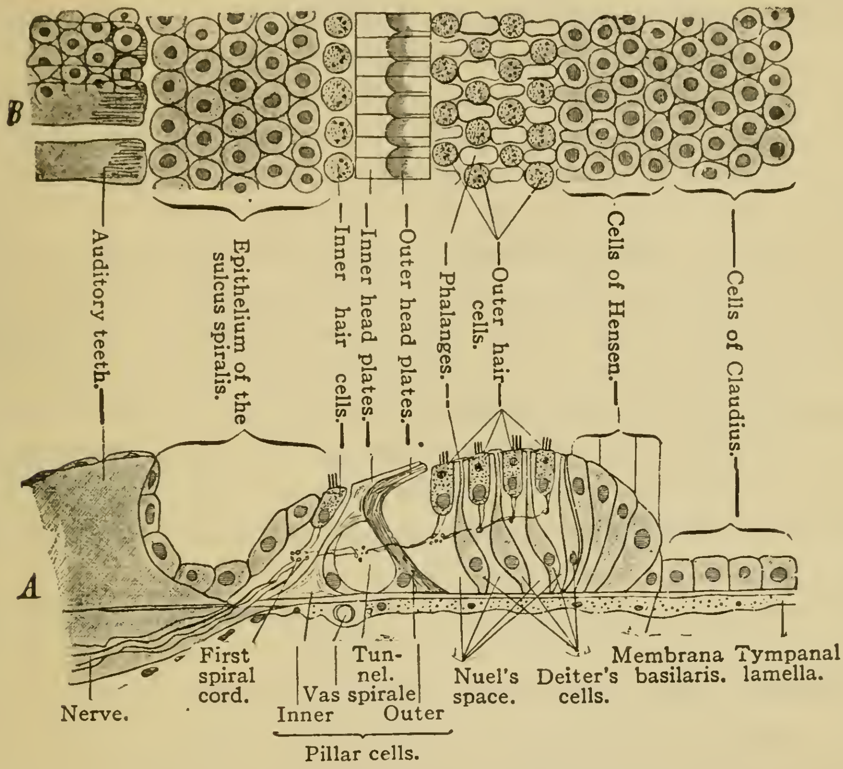

B
Auditory teeth.
Epithelium of the sulcus spiralis.
Inner hair cells.
Inner head plates.
Outer head plates.
Phalanges.
Outer hair cells.
Cells of Hensen.
Cells of Claudius.
A
First spiral cord.
Nerve.
Tun-nel.
Vas spirale
Inner
Outer
Pillar cells.
Nuel's space.
Deiter's cells.
Membrana basilaris.
Tympanal lamella.

FIG. 293.—DIAGRAM OF THE STRUCTURE OF THE BASAL WALL OF THE DUCT OF THE COCHLEA. (*Stöhr's Histology.*)

A, View from the side. *B*, View from the surface. In the latter the free surface is in focus. It is evident that the epithelium of the sulcus spiralis, lying in another plane, as well as the cells of Claudius, can be seen distinctly only by lowering the tube. The membrana tectoria is not drawn. The spiral nerves are indicated by dots.

the cleft is quite deep, and little projections, separated by lateral clefts, give rise to the **auditory teeth,** which number about 2500. These **teeth** and projecting areas are covered by *simple polygonal cells,* while the **clefts** are lined by *columnar elements.* The *inner* half of the **limbus** consists of a slightly projecting mass, the **superior**

lip, due to the sudden decrease in thickness, and a lower portion that continues over the bony lamina toward the basilar membrane; the *latter* is the **inferior lip.** Between these lies a little space, the **sulcus spiralis,** due to the sudden decrease in thickness of the periosteum. The **sulcus** is lined by *flat cells.*

The **basilar membrane** is covered on its tympanic surface by the **tympanic lamella,** made up of spindle-shaped cells and delicate fibers, representing an incomplete change to endothelial cells. This is continuous with the periosteum of the scala tympani. Above this layer is the *membrana propria,* that represents a greatly hypertrophied basement membrane and seems to support the epithelium upon its upper surface. The outer end of the basilar membrane is covered by the **cells of Claudius** that continue toward the outer wall and pass into columnar and flattened elements that are found upon the basilar crest. These cells possess spherical nuclei imbedded in a slightly granular and pigmented cytoplasm; they represent a continuation of the **cells of Hensen.** Between the limbus and the cells of Claudius lies the **organ of Corti,** composed of **neuro-epithelial** and **sustentacular cells.** This organ is divided into an inner portion, the **membrana tectoria,** and an outer part, the **zona pectinata.**

The **cells** of the **organ of Corti** are the **pillar, hair** and **sustentacular cells.**

The **pillar cells** are peculiar *S-shaped* elements possessing a striated body, surrounded by a narrow band of cytoplasm. The latter is thickened at the base (*tunnel side*), and in this part is seen the nucleus. The lower end rests upon the basilar membrane, and is expanded to form the **foot;** the upper end likewise undergoes an expansion, termed the **head.** These cells form two rows, inner and outer; they articulate above, and form a triangular canal called **Corti's tunnel.** This contains a semi-solid intercellular substance. The inner cell, being shorter, is more nearly vertical, and its head bears an *articular facet* for the reception of the *articular head* of the outer cell. The inner cells are more numerous and thinner than the outer, about 6000 to 4500, respectively. The head process of both cells continues externally as a thin, shelf-like process called the **head-plate.** Of these, the **inner head-plates** lie *above,* but are *shorter* than the **outer.**

The outer are called the **phalangeal processes,** and by their union with the **cells of Deiter,** form the **membrana reticularis.**

The **neuro-epithelial cells** are distributed upon the inner and outer surface of the pillar cells. They are the **hair cells,** and of these there are two rows, **inner** and **outer.** Like the hair cells of the preceding, and the neuro-epithelial cells of the nasal mucous membrane, they are about half the length of the sustentacular, or pillar cells, and are columnar elements containing a granular cytoplasm and an oval nucleus. The outer end has a cuticular border, from which about twenty hairs extend. The **outer cells** are longer and narrower than the **inner,** and more numerous. There are about 12,000 *outer* and 3500 *inner* hair cells. Usually one hair cell is present for each two pillar cells. The outer hair cells are found in three or four rows, which are separated by the ends of phalanges of Deiter's cells and the membrana reticularis. The inner row rests upon the outer pillar cells; the cells of the next row lie opposite to the rods, and the third row alternates, producing a peculiar *checker-board* appearance, the ends of the hair cells being separated from one another by the ends of the Deiter cells.

The **sustentacular,** or **Deiter cells** are **internal** and **external.** Each cell consists of a thin **pyramidal process** and a large **basal** part that contains the nucleus. The **intercellular spaces of Nuel,** between the cells of the organ of Corti, contain a substance like that in the tunnel of Corti. Internally, **Deiter's** cells pass through the entire layer, and are continuous with the cells of the sulcus. Externally, they form the phalanges that help produce the membrana reticularis. A surface view will show both sustentacular and neuro-epithelium; a basal view, however, will show only sustentacular elements. Just external to the Deiter cells are other sustentacular elements, the **cells of Hensen.** These extend to and continue with those of Claudius. Extending over the organ of Corti and arising from the upper lip of the limbus is a membrane composed of delicate fibers and interfibrillar substance. This is the **membrana tectoria,** or **Corti's membrane.** At one time this was part of the cells beneath, those of the sulcus and auditory teeth; it represents a *cuticular border.*

The divisions of the *auditory nerve* are *vestibular* and *cochlear.*

The *vestibular* arises from the *sacculus, utriculus, maculæ* and the *semicircular canals* (*cristæ*). These fibers are the dendrites of the cells in the ganglion of Scarpa which lies in the internal auditory

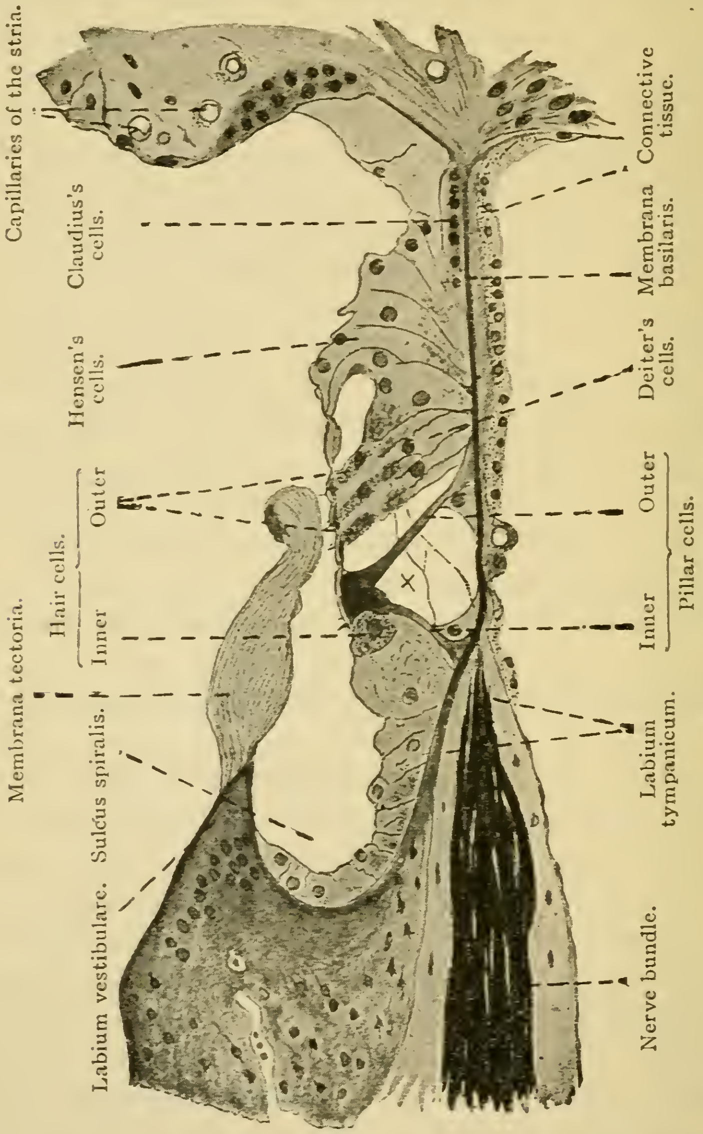

Capillaries of the stria.
Claudius's cells.
Hensen's cells.
Hair cells.
Outer
Inner
Membrana tectoria.
Sulcus spiralis.
Labium vestibulare.
Connective tissue.
Membrana basilaris.
Deiter's cells.
Outer
Inner
Pillar cells.
Labium tympanicum.
Nerve bundle.
×

FIG. 294.—CORTI'S ORGAN.

×, Tunnel of Corti traversed by nerve fibers. (*Stöhr's Histology.*)

meatus. The axis cylinders of these cells pass to the oblongata. The *cochlear* portion arises mainly in the *cochlea*, receiving some fibers from the sacculus and posterior semicircular canal, and is made up as follows:

In a little bony canal in the lamina spirale is a strip of gray nerve tissue that is called the **ganglion spirale** (*Corti's ganglion*). This consists of bipolar cells, one branch, the *dendrite* of which passes outward into the organ of Corti, while the other, the *axis cylinder*, passes through a minute canal in the axis to the central canal, where it meets other fibers from different levels. These pass to the base and to the internal auditory meatus, as the **cochlear branch,** and then to the oblongata. The dendritic branches of these ganglion cells form a plexus in the minute canal of the spiral shelf. Toward the organ of Corti the lamina is pierced by many canals called the **foramina nervosa** through which numerous fibers, the myenlinated dendritic branches, pass, along its inner epithelium, to the organ of Corti. Upon entering these canals, the myelin sheaths and neurilemmæ are lost, and the naked dendrites, in bundles, continue. Each bundle separates into two, one of which remains at the inner surface and the other passes along the outer side of the pillar cells. The latter lies in the tunnel. Other dendrites cross the tunnel and pass to the outer side of the outer pillar cells and form several bundles between the Deiter cells. From these various bundles, fibrillæ terminate in relation with the hair cells.

The *blood-vessels* supplying the internal ear is the *internal auditory artery* that passes into the internal auditory meatus with the acoustic nerve. Its two main branches are the *cochlear* and *vestibular arteries.* The *cochlear artery* gives off a branch, the vestibulocochlear artery that sends branches to the maculæ of the sacculus, the posterior ampulla and neighboring portions of the posterior semicircular canal, first part of the cochlear duct and utricle. The main portion of the artery passes into the modiolus and supplies almost the entire cochlea.

The *vestibular artery* supplies the sacculus, utriculus and semicircular canals; the capillary plexus is especially well developed in the neuro-epithelial areas.

The blood is collected by *venules* that have a course that corresponds somewhat to that of the arteries. The blood of the cochlear artery is carried from the organ by the *vena aqueductus cochleæ* and is emptied into the internal jugular vein. Some of the blood of the cochlear artery is carried by the internal auditory vein and emptied into the inferior petrosal sinus. The blood of the vestibular artery is carried by the *vena aqueductus vestibuli* and is emptied into the superior petrosal sinus.

Lymph vessels are few but lymph spaces are numerous and large in the internal ear. The space between the osseous and membranous labyrinths is an extensive lymph space and contains the *perilymph.* This space communicates with the subdural lymph space by perineural lymph vessels and vessels around the aqueductus cochleæ. The membranous labyrinth contains the *endolymph* and this can get to the subdural space through the endolymphatic duct and the aqueductus vestibuli.

CHAPTER XX

THE SENSES OF SMELL, TASTE, AND TOUCH

THE ORGAN OF SMELL

The **nasal mucosa** is divided into **respiratory** and **olfactory** portions. The *lower* portion of the **respiratory** area, called the **vestibule,** is lined by *stratified squamous cells* to the turbinated bone. Here a great many hairs, sebaceous and mucous glands that extend for a short distance, are encountered. Above the turbinated bone, the epithelium is of the *stratified ciliated* variety, and many goblet cells are present. The hairs at the external meatus are large and are called **vibrissæ.** The *tunica propria* contains much lymphoid tissue and an extensive venous plexus. Mucous and serous glands are also present in great numbers in the region of the turbinated bone and nasal septum; they are largest near the floor. The mucosa is 4 mm. thick in this area.

The **olfactory mucosa** is usually prominent on account of its yellow color, but this does not indicate the entire olfactory membrane. It is very thick, and ciliated cells no longer exist. It lies in the superior and part of the middle meatus of the nose covering the superior conchal process and the nasal septum. The epithelium is of three varieties, the **sustentacular, neuro-epithelial elements** and **basal** cells.

The **sustentacular** cells are irregular, and possess a *peripheral segment* which is cylindrical, and a *basal* that is narrow and irregular. The *peripheral segments* form a row of columnar elements. The oval nuclei form a regular band or row. The cytoplasm contains granules and pigment near the inner end, the former being arranged in rows. A *cuticular border* is present, and forms the **membrana limitans olfactoria.** The inner segments are irregular, and usually branch at their internal ends.

The **neuro-epithelial elements,** or **olfactory cells,** consist of peculiar, inconspicuous strips of protoplasm possessing an enlargement near the middle, in which lies a large, round nucleus. The latter form a band or zone of spherical elements. The peripheral ends of the rods extend, between the supportive cells, to the free surface as cylindrical processes that project beyond the surface. The basal ends are varicose and pass to the basement membrane. This end continues through the basement membrane into the tunica propria and continues as an amyelinated nerve fiber to the olfactory bulb. It represents an axone and an olfactory cell is a real nerve cell. In the olfactory bulb all of these processes terminate in and form part of the glomerular layer.

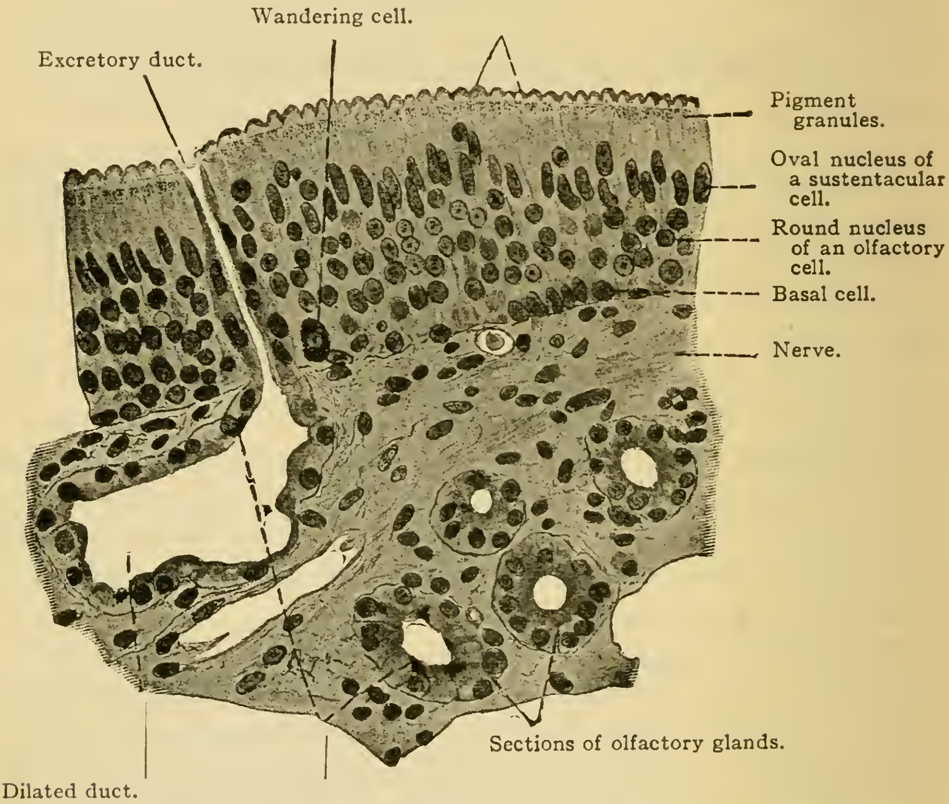

Wandering cell.
Excretory duct.
Pigment granules.
Oval nucleus of a sustentacular cell.
Round nucleus of an olfactory cell.
Basal cell.
Nerve.
Sections of olfactory glands.
Dilated duct.

FIG. 295.—VERTICAL SECTION THROUGH THE OLFACTORY REGION OF AN ADULT. × 400. (*Lewis and Stöhr.*)

The **basal** cells are small and irregular elements that send processes between the upper layers and, internally, rest upon the basement membrane. The cytoplasm is finely granular and may send short processes between the branches of the sustentacular cells.

The *tunica propria* consists of a loose, thick network of fibro-elastic tissue. This supports the racemose (serous) *glands of Bowman* whose functionating epithelium possesses a brownish, or yellowish pigment. These glands are numerous, forming a continuous layer. It also contains a plexus of myelinated nerve fibers.

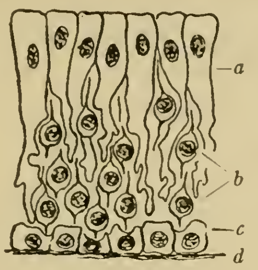


FIG. 296.—DIAGRAM OF OLFACTORY MUCOSA.
a, Sustentacular cells; *b*, neuro-epithelial elements; *c*, basal cells; *d*, basement membrane.

The **accessory cavities** possess a lining of *ciliated cells.* The mucosa is very thin, 0.02 mm., and it is firmly attached to the periosteum. Glands are very few in the mucosa of these cavities. These cavities comprise the *frontal*, *ethmoidal*, *sphenoidal* and *maxillary sinuses.*

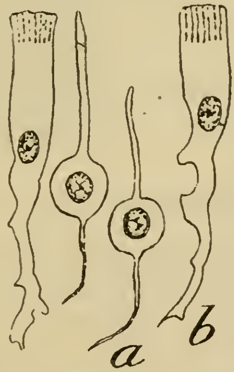


FIG. 297.—ISOLATED ELEMENTS OF THE OLFACTORY MUCOSA.
a, Neuro-epithelial cell; *b*, sustentacular cells showing cuticular border.

The *blood-vessels* are numerous. The arterial branches form a dense subepithelial plexus, including a network around the glands.

The veins are large in number and size, especially upon the inferior turbinate.

The *lymphatics* lie in the lower part of the tunica propria; in the olfactory area, an extra set of vessels occurs in the superficial portion. These communicate with the channels around the nerves.

The *nerves* are those of *ordinary* and *special sensation*. The *former* are derived from the *trigeminus* and do not connect with the cells. The *latter* form the *olfactory fila*, or *nerves*. The fibers of the olfactory nerves are the axone processes of the neuro-epithelial elements; these pass through the basement membrane to the tunica propria, to form small bundles that are surrounded by *perineural lymphatic sheaths;* from this position in the tunica propria they pass through the openings in the cribriform plate of the ethmoid bone and terminate in the *glomerular layer* of the olfactory lobe. These fibers possess neither myelin sheaths nor neurilemmæ.

THE SENSE OF TASTE

The **sense** of **taste** is due to the **taste-buds**. These are not restricted to the *circumvallate papillæ* of the tongue, but are found in the *papillæ foliatæ*, in the *ventral surface of the epiglottis*, at times in the *fungiform papillæ* and in the *soft palate* and *uvula*.

The organs are barrel-shaped, lie entirely within the epithelial layer of the mucosa and consist of *three* kinds of cells, the *sustentacular*, *gustatory* and *basal cells*.

The *sustentacular*, or *supporting cells* are elongated elements; the outer extremities are pointed and form the boundary of the *gustatory pore*. The basal extremities are broad and irregular and rest upon the basal cells, to which they may be connected by delicate protoplasmic processes.

The *gustatory cells* are of the *neuro-epithelial type*. These are slender, irregular strips of protoplasm in which the large centrally placed nucleus produces quite a bulge. The basal extremity of each cell is branched and connected to the basal cells by delicate protoplasmic processes. The peripheral extremity is continued as a delicate hair-like process that extends into the epithelial canal beyond the taste-pore and almost to the surface of the epithelium of the mucosa. The finely granular cytoplasm contains a deeply staining, rod-shaped nucleus.

The *basal cells* are flattened elements that lie at the base of the taste-bud. The cytoplasm is small in amount and extends as many processes that connect with the other cells of the taste-bud. The nucleus contains but little chromatin and the cells are supposed to be supportive in function.

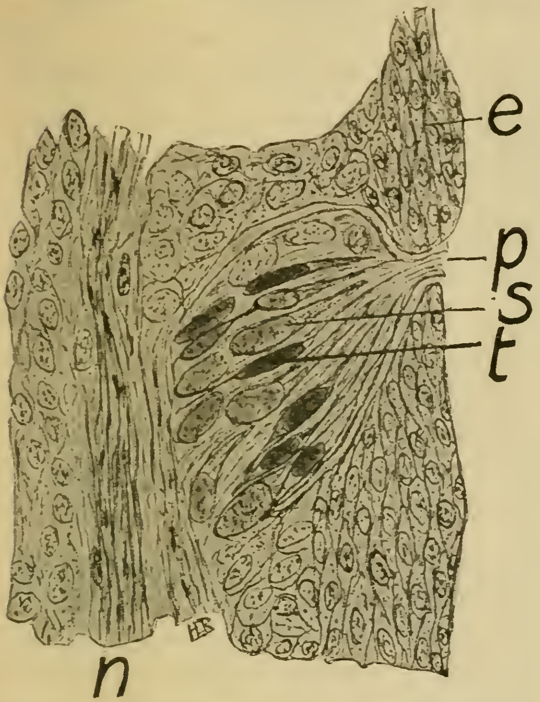


FIG. 298.—SECTION OF A TASTE-BUD OF A RABBIT.

e, Epithelium; *p*, taste pore with gustatory hairs; *s*, sustentacular cells; *t*, gustatory cells; *n*, nerve fibers. (*After Ranvier.*)

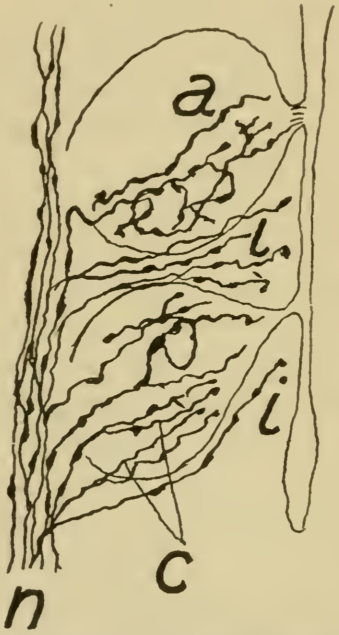


FIG. 299.—GOLGI PREPARATION OF THE NERVE FIBERS OF A TASTE-BUD.

a, Intragemmal fibers; *i*, *i*, Intergemmal fibers; *c*, circumgemmal fibers; *n*, nerve fibers. (*After Retzius.*)

The *nerve fibers* arise from the subepithelial plexus of nerve fibers. These terminal fibers end in *three ways.* Some enter the organ (*intragemmal*) where they divide into fibers that are varicose and end in knobs between the neuroepithelial cells. Others surround the taste-bud (*circumgemmal*) and the fibrils terminate upon the sustentacular cells. Others terminate between the epithelial cells of the neighboring mucosa (*intergemmal*).

THE SENSE OF TOUCH

The **sense of touch** is not limited to any special region, but it is best developed in certain areas, as the **palm** and **sole.** It is restricted to the skin, and represents a modification of general sensibility. In the papillæ of the skin, especially that of the sole and palm, are found the **tactile corpuscles of Meissner.**

These are elongated structures that measure from 100 to 180 microns in length and 35 to 50 microns in diameter. Each consists of a capsule of white fibrous tissue that encloses a number of flattened masses of protoplasm with transversely placed nuclei. One, or more, nerve fibers is connected with each organ and upon contact with the corpuscle the neurolemma is lost. The myelin sheath soon follows and the naked axone, after a spiral course, divides into a number of varicose fibrils that terminate in small bulbous enlargements near the capsule. These structures are found throughout the skin but are most numerous in the derma of the palmar surface of the finger tips. They may be as numerous as 20 to the square millimeter and are in the papillæ of the stratum papillare, just beneath the basement membrane. They are also found in the derma of the plantar surface, in the nipples, lips, glans clitoris and glans penis and the conjunctiva. They convey sensations of pain, pressure, warmth and cold. It is said that two sets of sensor fibers pass to them, one for light pressure and slight temperature changes and the other for pain and extreme temperature changes.

The **Pacinian corpuscles** (*Vater*) are also called *lamellar corpuscles.* Each consists of a *capsule, inner bulb* and *end-knob.* The *capsule* is composed of a great number of lamellæ of white fibrous connective tissue concentrically arranged and bound together by an intracapsular ligament. These lamellæ are from forty to sixty in number and the outer ones are more widely separated from one another than the inner ones. Each lamella is said to consist of both white fibrous and yellow elastic tissues and is covered upon both surfaces by endothelial cells, thus forming a series of lymph spaces.

The *inner bulb,* or *core* is a cylindrical mass of protoplasm that may show striations and nuclei. It is thought to consist externally of flattened nucleated cells surrounding the more homogeneous central portion. A single nerve fiber enters each corpuscle. As it pierces the capsule the neurolemma blend with this and the myelin sheath is lost when the inner bulb is reached. The naked axone, showing its fibrillation, in properly stained sections, passes through the core at the end of which it expands into a knob-like structure, the *end-knob.* In this the terminal fibrils form a dense meshwork.

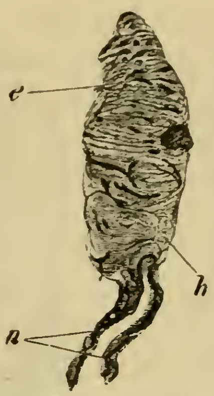


Fig. 300.—Corpuscle of Meissner from Great Toe of Man.
n, Myelinated nerve fiber; *h*, connective tissue sheath; *e*, varicosities. The nuclei are invisible. (*Stöhr's Histology.*)

If the axone divides in the core, the latter also divides. A small amyelinated nerve fiber has been found, by Solokoff, passing to the core and terminating upon it in a reticular manner.

A *small artery* and *vein* accompany the nerve into the corpuscle. The artery forms capillary vessels that form loops between the lamellæ; one capillary accompanies the nerve and courses along the outer surface of this for a variable distance. The blood is collected by a small vein that leaves at the nerve entrance.

These organs are visible to the unaided eye, measuring usually 2.5 mm. in length and 1 mm. in diameter. They are found in the deep parts of the derma, along tendons, around joints, in the peritoneum, in the mesentery (in lower animals) and in the pancreas of the cat.

The **conjunctival corpuscles,** or **bulbs** are spherical, oval or pear-shaped bodies in which the cells are not regularly arranged. The nerve fiber, upon piercing the structure, becomes amyelinated and passes through a central core of homogeneous protoplasm and terminates in a bulbous manner. The *core* is surrounded by a *capsule* that is composed of flattened cells. These organs average from 60 to 400 microns in length and may have as many as ten nerve fibers connected with one organ.

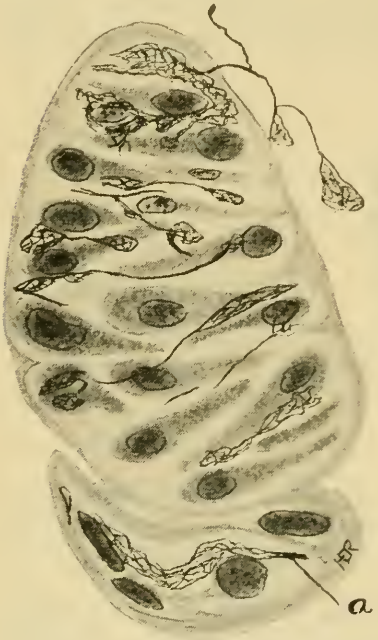


FIG. 301.—A TACTILE CORPUSCLE WITH ITS CELLS AND TERMINAL NEUROFIBRILS.
a. Axone. (*After Van de Velde.*)

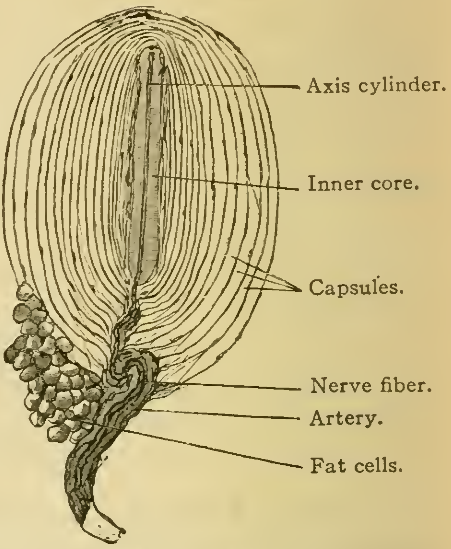


FIG. 302.—SMALL LAMELLAR CORPUSCLE FROM THE MESENTERY OF A CAT. × 50.
The nuclei of the capsule cells appear as thickenings. The myelin of the nerve fiber may be traced to the inner core.

The **genital corpuscles,** or **bulbs** are more complex. Each is divided into two to six knob-like parts. The nerve fiber enters the organ and divides into numerous branches each of which passes to a segment; here it may continue undivided or form a series of branches. These are surrounded by the capsular cells. These organs measure from 60 to 400 microns in length and 40 to 100 microns in diameter. They are found in the mucosa of the glans penis and glans clitoris and neighboring structures.

CHAPTER XXI

DEVELOPMENT OF FACE AND TEETH

The development of the face is a complicated process, a number of different fetal structures taking part therein. Just after the formation of the head-fold of the amnion there is an area, just precephalad to this groove, in *which* the ectoderm and entoderm are in contact. This is the *buccopharyngeal area.* As the head-fold of the amnion advances this buccopharyngeal area is folded ventral so as to form the ventral part of the *blunt-head process* (see Fig. 230, A, and C, p. 400). By this time this area has become a depression, the *oral depression*, or *stomodeum*, the floor of which is the buccopharyngeal membrane. This depression is present at about the twelfth day of intrauterine life. The floor of this depression sinks deeper and the margins become more pronounced.

At about the fifteenth day the lower boundary of the depression becomes formed upon each side into a finger-like process, called the **first branchial arch,** that soon divides into a shorter upper portion, the **maxillary division,** and a lower part, the **mandibular division.** The upper division forms now the lateral boundary and the lower the inferior boundary of the oral depression. At about the same time the tissues in the frontal region become projected in the form of a blunt mass between the maxillary divisions of the first arch, constituting the **nasofrontal proccess.** Thus the stomodeum has become a pentagonal fossa. At about the eighteenth day a second finger-like process makes its appearance beneath the mandibular portion of the first arch; this is followed by a third arch about the twenty-first day, a fourth by about the twenty-fourth day, and the fifth and last arch is formed by the twenty-eighth day. The last are less highly developed than the first, and while the lower ones are forming the upper ones are undergoing metamorphosis into their adult structures.

The changes that occur in the **branchial arches** will be considered first: Each arch consists of a core of *mesoderm* containing a rod of cartilage and a blood-vessel called the *branchial arch vessel;* externally the arch is covered by *ectoderm* and internally by *entoderm.* The arches are separated from each other by a *groove* or depression, internally, and externally, and spanning the groove is the *visceral cleft membrane* consisting merely of ectoderm and entoderm, so that no real complete cleft exists in the early stages of development; in aquatic animals these membranes do rupture to form the gill-clefts. On each side there are four *external* and four *internal* visceral grooves or, better, *branchial pouches.*

The first arch, as previously mentioned, divides into two portions, *maxillary* and *mandibular;* the maxillary part unites with nasofrontal process to complete the upper jaw; it itself gives rise to the bulk of the maxilla and most of the palate. The upper jaw is completed by about the fortieth to the forty-second day. The mandibular process unites with its fellow of the opposite side to form the entire mandible, union being completed by the end of the fifth week, or thirty-fifth day. In addition, the cartilage of the mandibular process gives rise to incus and malleus, and stylomandibular ligament.

The rod of cartilage of the second arch gives rise to the stapes, styloid process, stylohyoid ligament and lesser cornu of the hyoid bone.

The cartilage of the third arch forms the body and greater cornu of the hyoid bone.

The cartilage of the fourth and fifth arches unite and form a single mass, the thyroid cartilage of the larynx.

The first external branchial pouch persists only at its dorsal end to form here the external auditory canal. From both first and second arches in this region the pinna of the ear is developed. The remaining pouches are lost as the arches overlap each other from above downward. Occasionally part of a pouch persists as an enclosed cyst of ectoderm and this is called a *branchial cyst.* In case a pouch membrane ruptures and permits of a passage-way from the outside to the pharynx it is called a *congenital cervical fistula.*

The first internal pouch is formed into a tube with its outer end dilated into an irregular cavity, the *tympanic cavity;* the tube-like portion connecting this with the pharynx is called the *auditory tube.* That part of the first pouch membrane separating the external auditory canal from the tympanic cavity is the future *tympanic membrane*, or *ear drum.* In the middle of the ventral portion of the first pouch is found a projection, the *tuberculum impar*, which later becomes the anterior, or apical two-thirds of the tongue.

From the region of the second pouch (representing the ventral ends of the second and third arches) we find the tonsil and lateral recess of the pharynx developed, dorsally, while ventrally in the median line the entire of the thyreoid body is formed, and just lateral of this the dorsal, or basal one-third of the tongue by two masses (one on each side).

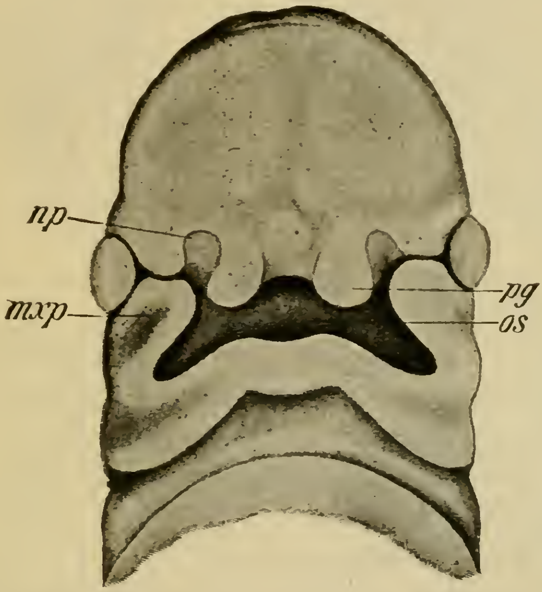


FIG. 303.—FACE OF AN EMBRYO OF 8 MM. (*McMurrich, after His.*)
pg, Globular (median nasal) process of nasofrontal process; *np*, nasal pit bounded externally by the lateral nasal process; *os*, oral pit; *mxp*, maxillary process of first branchial arch.

In the third pouch region (third and fourth arches) the thymus body, as two lobes, appears and also the superior parathyreoids.

From the fourth pouch (fourth and fifth arches) the lateral thyreoids, or postbranchial bodies and the inferior parathyreoids.

The **nasofrontal process** is at first a blunt mass of tissue projecting from the frontal region. As it grows down between the maxillary divisions of the first visceral arch, it becomes thickened along its margins, forming here the *median nasal processes;* each process contains a little depression that constitutes the *nasal pit.* In addition, two masses, the *lateral nasal processes,* develop from the nasofrontal process, at the orbital region, to form the lateral boundary of the nasal pits. Usually by the fortieth or forty-second day the nasofrontal process has filled the gap between the two maxillary processes of the first arch, and union of these parts is completed. As a result the nasal pits are separated from the mouth cavity. The derivatives of the nasofrontal process are the middle of the upper jaw (intermaxillary bones), the middle of the upper lip, the tip, septum, alæ and bridge of the nose and the vomer. The crevice between lateral nasal processes and the maxillary division of the first arch extends from the orbit of the nose cavity. When this crevice is closed a cord of epithelium is inclosed, and by hollowing out this cord of cells forms the nasolacrimal duct. If the lip portions of the nasofrontal process and first arch fail to unite, a *malformation, unilateral, or bilateral hare-lip,* is produced. If the bony parts within are affected, various forms of *cleft-palate* result.

The **palate** is developed in the form of three shelves, *two lateral* from the maxillary processes of the first arch and *one frontal, triangular, from the nasofrontal process.*

At about the eighth week union between the lateral shelves at the front end and the nasofrontal portions begin; by the ninth week union as far as the posterior border of the future hard palate is completed, by the eleventh week the soft palate is finished and by the end of the third month the uvula is complete. Various malformations may occur here, as *partial,* or *complete cleft-palate* and *bifid uvula.* Then after the upper jaw is completed two ridges appear upon each jaw, the *inner* represents the *gum* and the *outer* the *lip.*

The Teeth.—The teeth are developed partially (enamel) from the *ectoderm* and partially (dentin, cementum, pulp, and peridental membrane) from the *mesoderm.*

There are two sets of teeth in the mammals, **temporary,** or **de-**

ciduous, or **milk teeth,** and **permanent,** or **succedaneous teeth.** Such animals are *diphyodonts*. Animals that may develop teeth successively without regard to number are *polyphyodonts*.

In the former case the teeth are unlike, and the animals are *heter-*

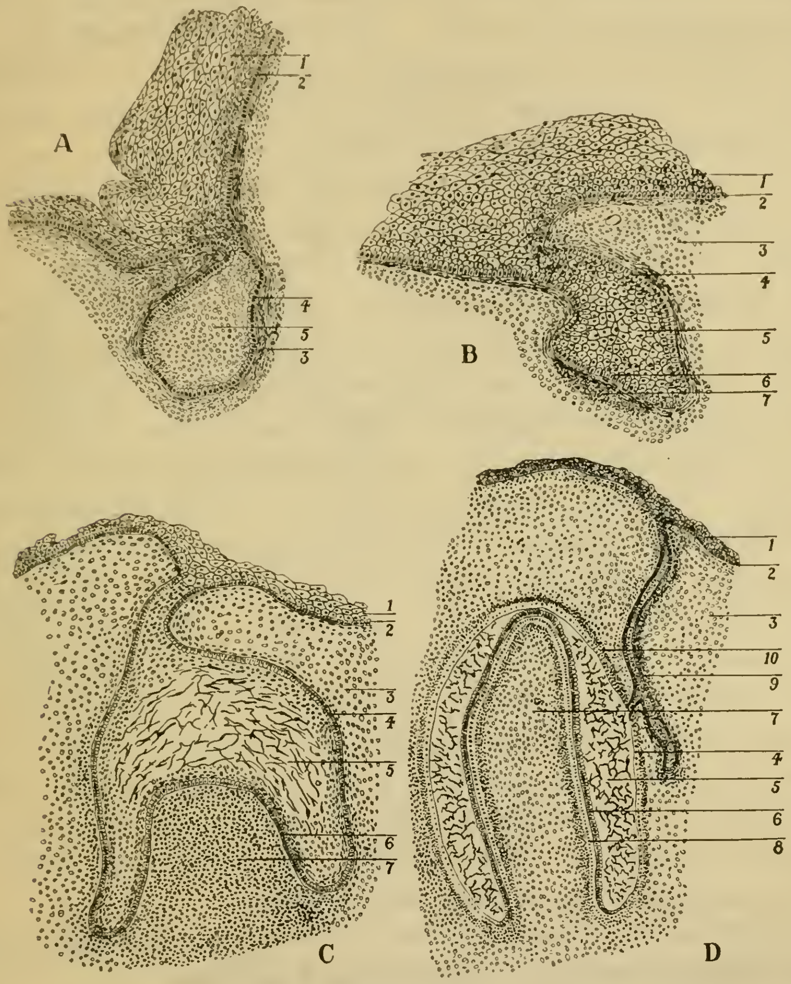


Fig. 304.—Four Stages of Tooth Development.
(*After Böhm, Davidoff and Huber.*)

A, Formation of the enamel from the dental shelf; B, later stage with early formation of the dental papilla; C, later stage showing enamel sac with its layers differentiating and the dental papilla well advanced; D, enamel sac completed (just preceding enamel formation) connected to dental shelf; dental papilla completed. 1, 1, 1, 1, oral epithelium; 2, 2, 2, 2, basal layer of same; 3, 3, 3, 3, mesoderm of jaw; 4, 4, 4, 4, outer layer of enamel organ; 5, 5, 5, 5, middle layer; 6, 6, 6, inner layer; 7, 7, 7, dental papilla; 8, layer of odontoblasts; 9, dental shelf; 10, follicular sheath.

odonts, while in the latter case the teeth are all alike and the class is that of *homodonts*.

The teeth begin to develop during the *sixth week* (shortly after the completion of the lower jaw). From the under surface of the thickened epithelium of the jaw a band of epithelial cells grows into the mesodermal core of the jaw. This is the **dental shelf,** the earliest indication of the developing teeth. Shortly after the formation of this shelf the epithelium at the area of thickening sinks in forming the *dental groove.* The dental shelf extends from one end of the jaw to the other and leans toward the median plane of the head, and from the *outer free* or *labial* surface ten little germs or buds develop, called the **enamel germs.** There are ten in each jaw, and they represent enamel organs of the temporary teeth. These buds appear successively: those for the central incisors first, then lateral incisors, first molars, canine, and second molars. The earliest buds appear during the seventh or eighth week. The enamel bud is at first flask-shaped, and its connection with dental shelf becomes smaller. Gradually the surface opposite to the dental shelf connection becomes invaginated by condensing mesoderm; the concavity deepens and a *sac* is thus formed, while at the same time the dental shelf connection becomes more attenuated. The sac consists of three layers, *inner*, *middle*, and *outer*. The mass of condensed mesoderm that has caused the sac formation of the enamel, but which lies now in the enamel sac, constitutes the *dental papilla*. During about the tenth week mesoderm in the immediate neighborhood of the enamel sac condenses to form a sheath for the whole structure, and this is called the *dental follicle.* Meanwhile the dental shelf becomes attenuated and tends to disappear.

The succeeding changes will be described under **Enamel Formation, Dentin Formation** and **Cementum Formation.**

Enamel Formation.—The **enamel organ** now consists of three layers: the **outer layer** is composed of simple columnar epithelial cells continuous with the inner layer of cells at the base of the organ. They play no part in the formation of enamel. The **middle layer** consists of a mass of stellate cells varying in thickness as Fig. 304 shows; these cells make up the bulk of the enamel organ and the meshwork formed by them is filled with a fluid. This layer likewise has nothing to do with the direct formation of enamel, but seems to have a nutrient function. Along the innermost portion of this reticular mass is a group of cells forming a layer called the **stratum intermedium.** This layer consists chiefly of spherical cells mixed with some columnar elements. Apparently the spherical cells have elongated to the columnar type, probably for the purpose of replacing cells that fail in the innermost layer. This stratum intermedium is looked upon as the reverse layer to the enamel-forming cells; the cells of this stratum are most numerous where enamel formation is most active.

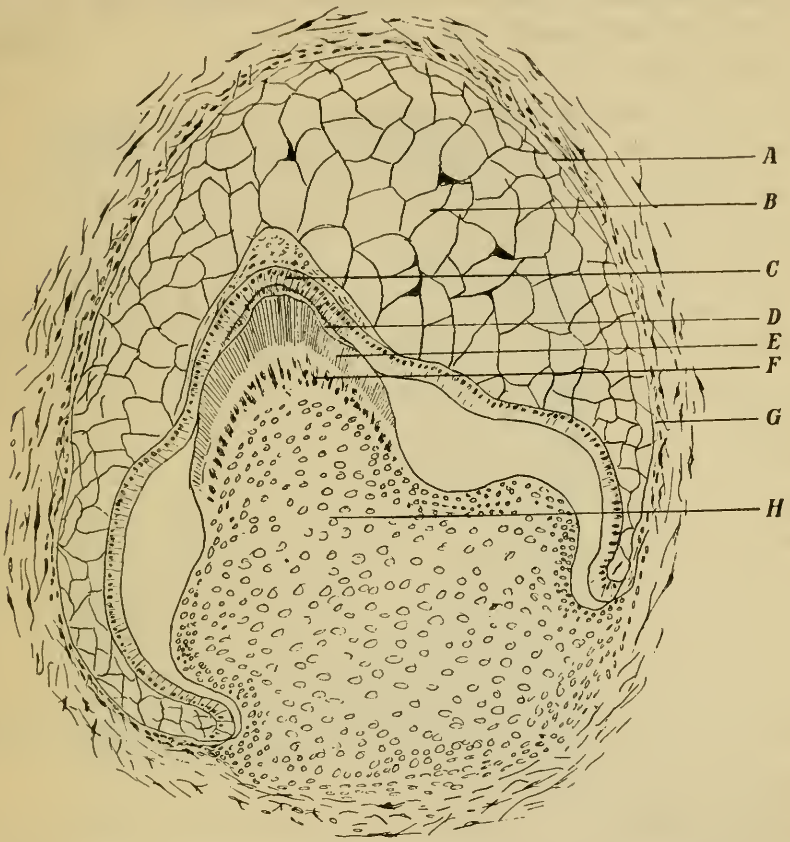


FIG. 305.—SECTION OF A DEVELOPING TOOTH OF A CAT EMBRYO. (*After Piersol.*)

A, Outer, *B*, middle, *C*, inner layers of enamel organ; *D*, formed enamel; *E*, formed dentin; *F*, layer of odontoblasts; *G*, follicular sheath; *H*, dental papilla, mesoderm.

The **inner layer** is composed of a single row of tall slender, columnar elements; these form a closely packed unbroken layer surrounding the dental papilla and are termed the *ameloblasts.* The nuclei lie in the peripheral portion of the cells.

Enamel deposition begins during the *sixteenth week* of intrauterine life, in the temporary teeth. According to Tomes and others, the inner ends of the enamel cells become calcified and *converted directly into enamel.* An organic matrix is formed in which the enamel is deposited, probably in the form of calcoglobulin globules. The organic matter disappears, leaving the homogeneous, inorganic material representing, no doubt, the fused globules of calcoglobulin. According to Andrews and others, the enamel is secreted from the cell in some form (calcoglobulin), and this solidifies and forms outside of the cell. The first, however, seems to be the more acceptable explanation. Enamel is formed from within outward, so that the youngest enamel is upon the surface while the oldest is next to the dentin.

Capillary blood-vessels have been noted in the enamel organ by Bromell. It seems that before calcification begins that vessels are absent; with the formation of enamel vascularization of the enamel organ begins and is said to persist until the tooth erupts. By the time that the tooth begins to erupt, or, at the latest, when completely erupted, the enamel is fully formed.

Between the enamel organ and the surface of the dental papilla is a layer of homogeneous substance called the *membrana preformativa.* Reference to this will be made later.

Dentin Formation.—The **dentin** is derived from the dental papilla; this structure is composed of embryonic connective tissue in which four different kinds of cells are found. Upon the surface of the papilla will be found a single layer of flask-shaped cells, the *odontoblasts.* These form the *membrana eboris* from which the dentin is derived. The basal portion of each cell is directed toward the papilla, or centrally, and contains the nucleus. Each cell possesses processes; those which are directed toward the enamel organ constitute the ultimate *dental fibers.* These cells are differentiated shortly before the formation of dentin begins. Just beneath the layer of odontoblasts the papilla is practically devoid of cells; beneath this, however, there is a cellular area of mixed cells and then again a central area containing but few cells.

Dentin is first formed at the cutting, or occlusal surface and during the *sixteenth week* of intrauterine life. The dentin seems to be a *secretion* from the peripheral ends of the odontoblasts so that the processes in this region are surrounded by the lime salts, thus forming the *dental sheaths* and *tubules;* the odontoblasts are always beyond the area of dentin formation. The dentin is laid down from without inward, and in areas where dentin formation is incomplete spaces, that are called the *interglobular spaces*, remain. As the dentin becomes thicker (by encroachment upon the dental papilla) the dental fibers elongate and the tubules become correspondingly longer. The dentin in the crown portion is formed first, the root portion being completed last. When the teeth begin to erupt their roots are partially formed; by the time that the whole crown is exposed the fang is usually completed. In the case of the incisor

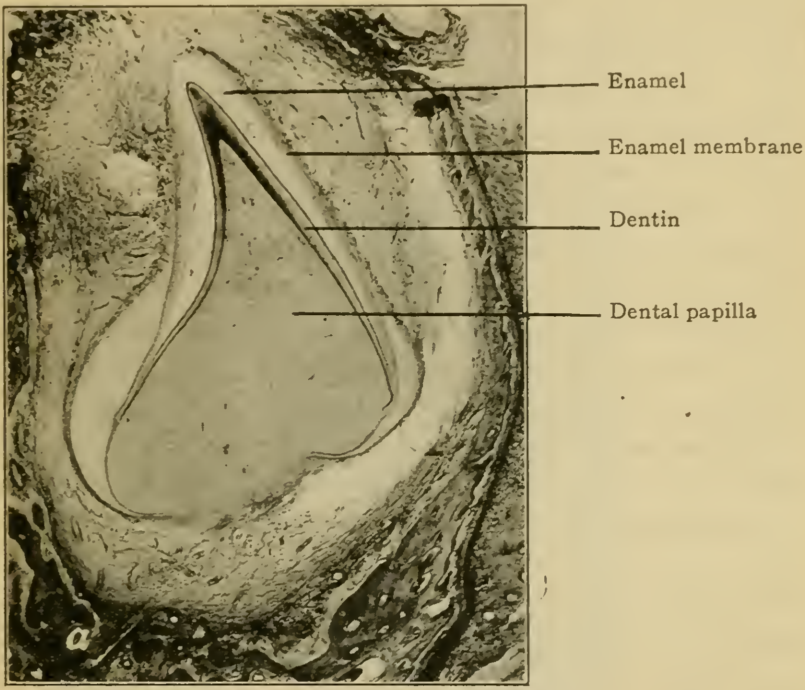


FIG. 306.—LONGITUDINAL SECTION OF A DEVELOPING TOOTH.
a, Bone of the alveolar process. (Photograph. Obj. 32 mm.)

teeth the roots are usually completed by the time that the tooth begins to erupt.

Cementum Formation.—The **cementum** is also of mesodermal origin. As the enamel organ becomes invaginated by the dental papilla the mesoderm immediately surrounding the enamel organ condenses to form a sac-like covering, the **dental follicle.** This structure gives rise to the cementum and the alveolar process of the jaw and its remains constitute the **peridental membrane.** The follicle is formed shortly after the tenth week. During the earlier stages of development the dental follicle covers the entire enamel organ and is connected with the dental papilla at its base. The follicle upon its *outer* surface forms *bone,* and upon its *inner* surface forms the *cementum* of the tooth. As the enamel organ grows the follicle seems to recede from the cutting edge until the neck portion is reached; at this point it remains, and as the root is formed by the dental papilla the follicle forms the cementum until the full length of the root is reached. The process of cementum formation is like that of bone, a *secretion,* and layers are formed as described in the section on the structure of cementum. The cementum and bone of the jaw are developed from the dental follicle, or *peridental membrane,* at the expense of the latter, it becoming thinner as the cementum and alveolar bone increase in thickness.

The temporary teeth begin to erupt from the sixth to the eighth month after birth and the set is usually completed by the twenty-fourth to the thirtieth or thirty-sixth month. The order of eruption is as follows:

Central incisors, sixth to eighth month.
Lateral incisors, seventh to ninth month.
First molars, twelfth to fourteenth month.
Canines, sixteenth to eighteenth month.
Second molars, twenty-fourth to thirty-sixth month.

The **permanent teeth** are thirty-two in number. The difference in number of the two sets and later appearance of added teeth is due to the fact that the jaw at certain periods will accommodate only a certain number of teeth, and any attempt to hurry their appearance will interfere with the dental arch. Of these permanent teeth, the *molars*, twelve in number, are *not succedaneous* teeth at all, but *primary* teeth as will be explained later. The germs for most of the permanent teeth are formed during intrauterine life.

During the *sixteenth week* a bud appears at each *end* of the dental shelves; these buds are the germs for the *first permanent molar* teeth. During the *seventeenth week* the germs for the *central incisors* appear from the *lingual* surface of the dental shelf, opposite the point of formation of the corresponding temporary tooth; the remaining succedaneous teeth follow in order of their eruption. The enamel organs undergo the same changes as previously described, with the exception that the process is somewhat slower, making their eruption somewhat later. As was stated above, the germs for the first permanent molars appear at the *ends* of the dental shelves and so have no forerunners; the germs for the *second molars* are developed from the

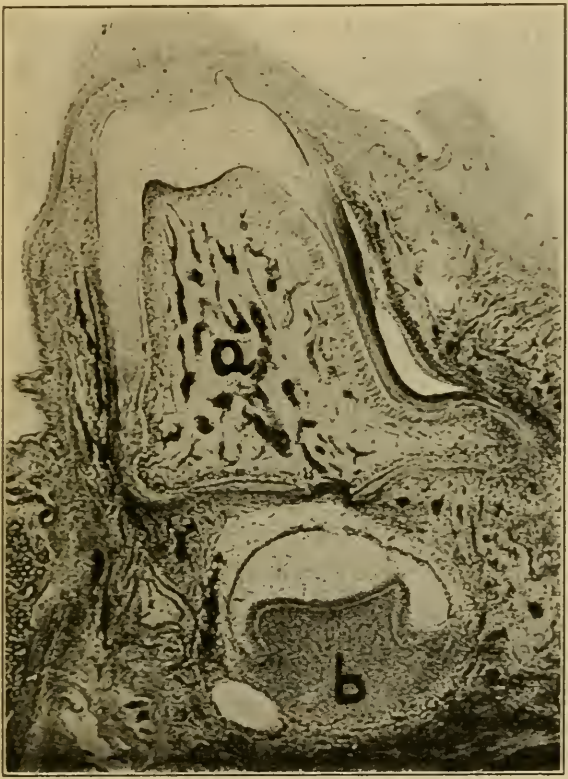


FIG. 307.—SECTION OF JAW SHOWING THE TEMPORARY (*a*) AND PERMANENT (*b*) TOOTH GERMS. (Photograph. Obj. 32 mm., oc. 5 X.)

neck of the enamel organs of the first molar during the third to the fifth month after birth; the enamel sacs for the *third* permanent molars appear from the neck of the enamel sacs of the second molars during the third to the fifth year after birth. All of the molar teeth, therefore, have no predecessors, and, are then, *primary* and *not succedaneous* teeth.

The first permanent molar tooth is the first one of the second set to appear; the order and times are as follows:

First molar, sixth year.
Central incisors, seventh year.
Lateral incisors, eighth year.
First premolars, ninth year.
Second premolars, tenth year.
Canines, eleventh to twelfth year.
Second molars, twelfth to thirteenth year.
Third molars, seventeenth to twenty-fifth year.

The eruption and succession of the teeth are by no means simple processes. As the tooth germs develop they at first lie in a groove of the jaw, covered merely by the gum; gradually transverse partitions of bone form so that the entire tooth is ultimately incased in the bone of the jaw. The bone intervening between the tooth and the gum amounts to but a thin lamella that is completed shortly before the tooth is to erupt, except in the region where the gubernaculum passes to the gum. As eruption is to take place, that bone which is last formed (over the cutting edge) is resorbed so that there is no interference with eruption.

The process of eruption is as follows: The bone covering the labial surface of the crown is resorbed until fully one-half of the surface is exposed; this is followed by the resorption of the bone on the lingual surface but here the process is slower and less complete, leaving some bone to protect the germs of the permanent teeth underneath. As a result of this process the crown apparently grows through the gum when in reality the gum becomes stretched over the tooth by the disappearance of the bone beneath. As the resorption continues until the crown is exposed, new bone is laid down about the base of the tooth to strengthen its position. According to some writers the tooth erupts by the growth of the root forcing the crown above the gum surface. When one considers that in the temporary and permanent incisor teeth the roots are completed by the time eruption occurs, this force cannot be counted upon as a factor in the eruption of the teeth. It might play some part in the eruption of the other teeth, but even this is doubtful.

From the eruption of the second temporary molar tooth until the fourth year the teeth are practically quiescent. From the fourth year on the temporary teeth begin to decalcify and drop out to make room for the permanent teeth. The process of decalcification is one of absorption; it begins in the apical portion of the tooth and advances to the enamel line. The central incisors are the first affected, at about the fourth year, and the others follow in order of their eruption. As a result of this process the root becomes absorbed and the hold of the tooth upon the jaw becomes weakened; ultimately merely an enamel cap remains; this process extends over a period of about three years for each tooth, going on simultaneously or successively in the various teeth. Some claim that the process of resorption of the roots is due to the pressure exerted upon the root by the permanent tooth beneath. This does not, however, seem to be the cause, for in cases of absence of the succedaneous tooth the process of absorption of the root of the temporary tooth occurs as usual.

The permanent teeth follow the temporary successively as the latter are lost. As the jaw gradually increases in length there is a second permanent molar added at the twelfth to the fourteenth year and a third one at the eighteenth to the twenty-fifth year.

The permanent teeth erupt in the same manner as the temporary organs; that is, by the absorption of the bone from the crown portion. As this process of absorption occurs during the eruption of both sets the jaws would become thinner from above downward; to offset this nature adds below more than is absorbed above so that the dimension from above downward increases up to the prime of life. As the second set is gradually lost bone is not replaced as rapidly as lost so that in an old jaw the alveolar processes are lost (showing the absorption from above downward) and the vertical dimension decreases.

Connected with the permanent tooth is a structure, the **gubernaculum dentis**, that seems to be of importance. It is a fibrous, cord-like structure attached to the apex of the tooth-sac and ends at the epithelium of the gum. It seeme to direct the follicle by its tension and also to indicate the direction of eruption, and to maintain the tooth in position.

In regard to *malformation* of the teeth, both sets may fail to appear, or the succedaneous teeth alone may not develop; again individual teeth may be absent, or a third set may appear after the second has been lost. What is more common than the latter is a duplication of some of the permanent teeth forming a row within the normal set; a fourth molar may appear if the jaw is long enough to accommodate it. Wisdom teeth are frequently absent. Malformations of the root may be in the form of an additional root or the fusion of several to form one massive root. Again, the teeth may be united by *fusion* (if before birth) or *concrescence* (if after birth). If two teeth are found in a single sac the condition is known as *geminous teeth.*

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